AGILE PORT AND HIGH SPEED SHIP TECHNOLOGIES

FY05 FINAL SUMMARY REPORT
Vol. I - PROJECTS 3-6 and 8-10

Submitted to:

Office of Naval Research
875 North Randolph Street, Room 273
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In fulfillment of the requirements for:
FY 2004/2005 Cooperative Agreement No. N00014-04-2-0003
Agile Port and High Speed Ship Technologies

FY 05 Project 05-1
Technical Coordination and Planning

Classification: Unclassified

Prepared and submitted by:
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July 2, 2008

CENTER FOR THE COMMERCIAL DEPLOYMENT OF TRANSPORTATION TECHNOLOGIES (CCDoTT)
California State University, Long Beach

July 2, 2008

Dr. Paul Rispin, Program Manager
Office of Naval Research, Code 331
875 North Randolph Street, Room 273
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Dear Paul,

Re: CCDoTT FY05 Deliverable, Project 05-1, Task 1.1
Deliverable 1.1c – *FY05 Final Summary Report Vol. I – Projects 3 - 6 and 8 - 10*

Dear Paul,

In accordance with Cooperative Agreement N00014-04-2-0003, we are pleased to submit the above referenced deliverable.

This document contains summaries of seven projects performed during the CCDoTT FY05 program cycle, the majority of which were completed in January, 2007. The three remaining FY05 projects are:

Project 05-1: Technology Coordination and Planning
Project 05-2: Technology Transition and Outreach
Project 05-7: Pacific Northwest Agile Port System Demonstration

Volume II of the Final Summary Report covering activities on these projects will be provided upon their completion.

CCDoTT hereby requests clearance for unlimited distribution of this deliverable.

Your comments on this document are appreciated.

Regards,

Steven Hinds

for Stan Wheatley
CCDoTT Principal Investigator

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14. ABSTRACT

This report covers a multi-project program of research focused on high speed ship (HSS) and agile port (AP) technologies. The HSS program continues to develop neural networks based multidisciplinary design optimization tools critically needed for the design of high speed multi-hull vessels. The axial waterjet project conducted a self-propulsion test to define the hydrodynamic performance characteristics of the advanced-design axial-flow propulsor. The Heavy Air Lift Seabasing Ship (HALSS) study focused on design and model test results. A study was performed on tools to create a ship motion and dynamic load calculation program to predict structural loads of high-speed ships suitable for multi-hulls. The Alternate Power study sought to correlate and consolidate the various technical and economic assessments. A study was conducted to demonstrate the preliminary market, economic, and technical feasibility of a commercial short sea shipping service on the Pacific Coast. In the AP sector a study was conducted to determine the compatibility of an Electric Cargo Conveyor (ECCO) magnetic levitation cargo transportation system to port requirements.

15. SUBJECT TERMS

CCDoTT, Agile Port, Agile Port System, High Speed Ship, High Speed Sealift, Maglev, Magnetic Levitation, ECCO, Electrodynamic Container Conveyor, CFD, MDO, Neural Networks, Axial Flow Waterjet, HALSS Trimaran, Seabase, SSS, Short Sea Shipping

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AGILE PORT AND HIGH SPEED SHIP TECHNOLOGIES

FY05 FINAL SUMMARY REPORT
Vol. I - PROJECTS 3-6 and 8-10

FY 05 Project 05-1, Program Element 5.05
Technical Coordination and Planning

Task 1.1 Project Oversight
Deliverable 1.1c - Final Summary Report

Submitted by:

Stan Wheatley, Managing Director
Center for the Commercial Deployment of Transportation Technologies
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This material is based upon work supported by the Office of Naval Research, under Cooperative Agreement N00014-04-2-0003 with the California State University, Long Beach Foundation, Center for the Commercial Deployment of Transportation Technologies (CCDoTT).

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Executive Summary

1.0 Introduction

The FY05 CCDoTT program addresses eight technical development projects and two administrative tasks within the Agile Port and High Speed Ship technology sector. As of this writing, seven of these technical projects have been completed in accordance with contract terms and conditions.

The FY05 Final Summary Report is being broken into two parts. Part I is this primary document that reports on the completed projects. Part II will cover the open project, Pacific Northwest Agile Port System Demonstration (Project 05-7) and the two administrative projects, Technical Coordination (Project 05-1) and Technology Transition and Outreach (Project 05-2). The administrative projects will be left open to cover administrative requirements relating to the open technical project and will be closed when the open technical project is closed.

The Pacific Northwest Agile Port System Demonstration (Project 05-7) has become delayed due to changing requirements directed by the United States Transportation Command (see discussion under Project 05-7). It is anticipated a new statement of work will need to be developed to adjust requirements and deliverable schedules. A modification to the Cooperative Agreement and an extension of the project will be required at which time Part II will be submitted to close out Project 05-7 and the related administrative support projects. The FY 05 program cycle can be closed out at that time.

The Executive Summary seeks to convey the principle issues and accomplishments achieved in the technical projects.

1.1 Project 05-3: The Evaluation and Implementation Plan for Southern California Maglev Freight System

This project builds upon work performed in the previous study that determined the technical feasibility of a high-speed Maglev system to expedite the flow of containers from and to the Ports of Los Angeles and Long Beach to an inland depot/port at Victorville, California. Having determined the conceptual and technical feasibility of a Maglev system, this continuation project focused on determining if the proposed system is competitive with, and can be designed to support, existing port infrastructure in conjunction with a variety of conventional infrastructure improvement scenarios.

The objectives of this phase of the project are clearly established in the project tasks as follows:

1. Demonstrate Maglev Competitiveness with Existing Transportation Infrastructure
2. Demonstrate Maglev Compatibility with Existing Port Facility
3. Formulate an Approach to Constructing a Maglev System and Perform a Marketing Study on that Projected System

As we began the study, the Port of Los Angeles became aware of the Maglev Feasibility Study completed last year and approached CCDoTT regarding the potential use of Maglev technology within the port. We were able to fully exploit this situation by lining up the Port with both the CSULB College of Engineering for concept design, and General Atomics for detailed engineering design and an operating Maglev prototype. The result was a study that provided a detailed engineering plan for an intra-port cargo movement system from a designated point supporting terminals to a proposed Southern California International Gateway (container intermodal facility). This study is the first cargo maglev study, or any advanced technology study, to be accomplished by the Ports of San Pedro Bay. While, specifically, this was a diversion from our initial intent of focusing on the long range cargo movement to an inland port, it met the objectives of compatibility of a maglev system within the port and established the competitive base of the system. The marketing study further supported the competitive requirement. The unexpected result was significant local, regional, state and federal government interest and the establishment of Maglev technology as a viable cargo movement option.

The next project will focus on specific system requirements to accommodate port, rail and intermodal support requirements of a fast moving and high throughput system. Additionally, the growing support indicates a need for an appropriate business plan to be included in the study.

1.2 Project 05-4: Automated Multidisciplinary Design Optimization Method for Multi-Hull Vessels

This project extends the ongoing CCDoTT work in Multi-Disciplinary Design and optimization (MDO) for multihull vessels, to the next phase. The major elements that are developed and used in the MDO process are advanced multi objective multi-criteria optimization, and neural networks. The overall optimization approach is based on the well defined Systems Engineering concept which is extensively used in aerospace industry. The systems engineering approach consists of synthesis level and subsystem level analysis and optimization. The outcome of the synthesis level definition will be a set of objectives, requirements and design constraints which will be imposed on subsystems. Like at the system level, the definition of the subsystems involves many disciplines and, therefore, requires a Multidisciplinary Design Optimization approach.

This report summarizes the development of a synthesis level Multidisciplinary Design and Optimization (MDO) tool for multi-hull ships. The MDO tool is unique in utilizing advanced multiobjective optimization methods, neural networks, and in its broad scope, integrating powering, stability, seakeeping, structural optimization, cost and payload capacity into a single design tool. The method is a comprehensive and efficient way for the designers to analyze various requirements at the preliminary design stage. Multiobjective optimization results are presented in the form of Pareto optimum solutions, allowing the designer to select the optimum solution of interest. The method is applied to several multi-hull ship concepts. Detailed studies are conducted in order to determine the best approach for the application. Improvements to the neural network developments and optimization process are also presented. Details of various aspects of the MDO tool are described in four deliverable reports that have been submitted. Extension of the method to subsystem level is planed for the next phase of the program.

The next proposed effort will center on the development of multi-disciplinary designs and optimization tools for innovative multihull ship designs such as JHSV - Joint High Speed Vessel (Intra Theater Ship), Seabasing (HALSS), and Short Sea Shipping (SSS) concepts. These tools will provide a rational procedure for assessing the military and commercial effectiveness of these concepts, based on their particular mission profiles and constraints. They are also applicable to other high-speed ship concepts. JHSV, HALSS and commercial SSS ships of different types, including trimarans will be considered for application of the developed MDO method. Building upon the results of the current FY05 program, the FY06 program consists of improvement of the Synthesis Design Model (SDM), by incorporating hull forms generation methods, seakeeping using Neural Networks (NN), and refined powering taking into account the hull form definition.

1.3 Project 05-5: Waterjet Self-Propulsion Model Test for Application to a High-Speed Sealift Ship

The proposed project represents Phase IV of an ongoing program for the development of an advanced axial-flow waterjet propulsor for the high-speed sealift application where waterjet propulsion is considered the only realistic choice. Axial-flow waterjets are believed to be a critical enabling technology for the weight-sensitive, slender hulls of high-speed ships.

The overall objective of the proposed work was to test a self-propelled model in a towing tank to completely define the hydrodynamic performance characteristics of an advanced-design axial-flow waterjet propulsor. Measurements were used to verify design predictions, provide off-design performance information, and yield detailed flow field data for use in understanding the behavior of the propulsion system design as installed in the hull model. Data will ultimately be scaled to the 600 ft. prototype sealift ship design developed in Phase II, whose waterjet design was water tunnel model tested in Phase III. That data was then used to predict performance of an operational system at full-scale. The development of a database with a significant quantity of model to full-scale data correlations is a matter of great importance to improving levels of confidence and predicting waterjet system performance for advanced high-speed applications.

CCDoTT has supported a multi-phase effort to develop a large axial-flow waterjet design for application to high-speed shipping. Commercially available large waterjets have been based on mixed-flow pump designs, which result in a much heavier and wider waterjet system than an axial-flow waterjet system. Axial waterjet units have a 15-20 percent weight advantage over comparable mixed-flow designs because of their straight-through flow design does not require any radial growth that adds significant weigh to the mixed flow type pumps. Weight is a critical item on high-speed ships; therefore, the benefit of a much lighter axial waterjet system is obvious for high-speed ships. Since high-speed ships favors narrow hulls with high length-to-beam ratios, there is a problem having enough transom width to install the requisite number of waterjet units to absorb the significant amounts of power that can be required for high speed. If the transom must be widened to accommodate the waterjets, increased transom drag will result. The CCDoTT axial waterjet design is significantly narrower than a comparable mixed-flow design, and generally three axial waterjets can fit in the same transom width that could only accommodate two comparable mixed-flow waterjets. The need for axial-flow waterjets is evident, and this phase of the CCDoTT effort looks at the sizing and performance impact of applying the CCDoTT axial waterjet design to a representative high-speed hull. This was accomplished by performing model self-propulsion testing using a representative high-speed catamaran hull model with scaled operating waterjet inlets, as this would have the most immediate interest.

The overall self-propulsion test objective is to completely define the hydrodynamic performance characteristics of the CCDoTT advanced-design axial-flow waterjet propulsor as installed in a suitable high-speed craft. Self-propulsion model testing of a single catamaran demi-hull with a pair of operating scaled waterjet inlets was undertaken. The baseline hull was a representative 40-knot catamaran design, but only a single hull was tested since the main area of interest was the inlet-hull interactions. The CCDoTT axial waterjet pump was evaluated for its sizing and performance in this representative high-speed catamaran hull application. A model of the CCDoTT axial waterjet pump had been tested separately in the water tunnel at NSWCCD to establish its hydraulic and cavitation performance characteristics[1]. Combining the water tunnel pump results with the scaled model hull results will establish the sizing and performance of a CCDoTT axial waterjet installation. The water tunnel tests established the design point head and flow coefficients for the CCDoTT axial pump design and indicated a pump hydraulic efficiency of no less than 91.8 percent. This information enables the axial waterjets to be scaled to any craft speed and power application of interest using programming that accounts for the other waterjet system considerations such as inlet losses.

The waterjet inlet is the interface between the waterjet pump and the external hull flow and is in need of further understanding, since its arrangements and design can have a big impact on high-speed shipping. Waterjet inlet losses affect the waterjet system performance and powering, while keeping inlets size and volume requirements to a minimum will save important space and weight but need to be considered with respect to impacts on inlet performance. The next phase of this project will focus on this important area.

1.4 Project 05-6: High Speed Trimaran Technology Development and Application for Benchmark Design Validation of Heavy Air Lift Seabasing Ship (HALSS)

This project is an ongoing CCDoTT project. It examines the feasibility of designing a 35-knot ship capable of delivering early entry of combat units up to 200 miles inland from a floating base 100 miles offshore. This is accomplished by loading, fueling, launching and recovering C-130J aircraft, while carrying enough cargo, troops and fuel to allow the aircraft to move 8,000 tons of troops and materiel to Joint Operating Theater 300 nautical miles away during 10 days of flight operations. The ship can also launch and recover US Army HOVER BARGEs and helicopters, and accomplish a Strategic Mobility and Combat Logistics mission including transport of Marines and their helicopters. The ship is designated HALSS (Heavy Air Lift Seabasing Ship).

This phase of the study includes general arrangement, machinery arrangement, hull forms development, powering estimates based on CFD calculations and model test results. Seakeeping analysis including motions and sea loads prediction, maneuverability analysis, basic structural design calculations and drawings, weight estimates, and intact and damage stability analyses, two building strategies suitable for several available shipyards, cost estimates, and recommendations for further design and engineering studies are also provided.

Technical Objectives and Approach**:**

1. Objective: Provide further HST technology development and validation by CFD calculations and model tests in the critical areas of hull form optimization, propulsion and structural design.
   Results: Various hull forms developed and analyzed. Based on CFD calculations optimized side hulls configuration was verified.
2. Objective: Investigate HST technology transfer to HALSS concept, which was evaluated in the course of the CCDOTT FY04 study. Reduce the technical and developmental risks in these applications by performing vital at this stage of HALSS concept development selected model tests to verify resistance characteristics.
   Results: MQLT, FLUENT and WASIM calculations were applied for powering and seakeeping predictions. Resistance and flow calculations were verified by comparison with results of model testing.
3. Objective: Complete technical feasibility analysis and risk assessment study to build and operate HALSS. Build strategy analysis and a construction plan.
   Results: Comprehensive buildability analysis was performed. Concepts of “one and multi unit(s)”were developed. Build plan and organization scheme were developed and reviewed by selected representatives of the shipyards. Cost estimate was prepared.
4. Objective: Develop the HALSS-C130 simulation model to demonstrate the operational scenarios of Trimaran based take-offs and landings. This capability will help verify the operational assumptions used in ship design and airplane modifications and support the refinement of the ship design subject to the C-130 requirements.
   Results: Operational simulation models of C-130J were developed and demonstrated. Trade-offs of various HALSS parametric features was performed.

In the next phase of HALSS development it is necessary to concentrate efforts in the following directions:

- Broad parametric evaluation of the HALSS technical requirements in coordination with US Army, USMC and US Navy mission requirements.
- Continue verification of the HST technologies and tools by performing flow measurements and seakeeping model tests.
- Further refinement of the HALSS technical solutions, including Hull Forms, propulsion in the side hulls, and selected engineering in the areas of flight deck structural and material designs.

1.5 Project 05-7: Pacific Northwest Agile Port System Demonstration

This is an ongoing open project. Results will be reported in Volume II of this deliverable upon project completion.

1.6 Project 05-8: Development of a Route/Mission Dependent Prediction Program for Rational Structural Dynamic Loads for High Speed Sealift Applications, Phase II-A

As commercial and military interest in High-Speed Sealift continues to grow, the need for reliable structural design and analysis tools is becoming extremely important. This project is the second phase of an ongoing project which would create a ship motion and dynamic load calculation program that would be suitable for use by designers, classification societies and the U.S. Navy to predict the structural loads of high-speed ships. The program will be suitable for both advanced monohulls and multi-hulls such as catamarans and trimarans.

The objective of this phase is to complete the ultimate load model and the reliability design methodology developed in Phase I by including the prediction of slamming and impact loads for the practical design of structure for advanced high-speed vessels.

The proposed work is a natural extension of the work already funded (by CCDoTT) and completed during the Phase I effort, for which a reliable frequency-domain ship motion and dynamic loads prediction method was developed for both high-speed monohulls and multi-hulls. Probabilistic methods were used to determine the most appropriate method for extreme value estimation from the statistics calculated by the frequency-domain program in Phase I. Under the proposed Phase II work, this frequency-domain program was combined with a deterministic time-domain structural slamming program to establish a prediction model for overall loads.

Under the current Phase-II-A efforts, candidate high-speed hullforms were identified along with a determination of their seaway motions for the most probable environmental and operational conditions that could lead to slam events. In addition, slam-induced load estimation algorithms were developed, and a test case was executed to determine the corresponding wave parameters and vessel motion responses in the time domain and to obtain the corresponding slam loads.

Overall, the strip theory frequency-domain model was found to provide an acceptable level of fidelity for the motions data. It was verified that SHIPMO output is equally credible for both high-speed monohulls and multihulls. Hullform comparisons provided confidence in the motions response data and the probable route/mission elements for slam events that could be carried through to the estimation of the slam loads. Another conclusion derived from the hullform validation effort was that the interference effects between the hulls for the multihulls has little significance in influencing ship motions and loads in the vertical plane, especially in the high-speed ranges where the wake interferences are minimal to none due to higher speeds of the vessel.

The development of a slam prediction methodology and the associated algorithms, and its implementation on a high-speed hullform, clearly demonstrated the viability of the procedure.

This provides the basis for extending the procedure to other hullforms and allows the development of an integrated program with an associated time-domain simulation tool.
It was also obvious from discussions and inputs from NSWC-CD and ABS that all branches of the maritime community that deal with high-speed vessels can benefit from the development of a tool-set that can provide early-stage design load estimates for high-speed multihulls which is rationally-based and easy and cost-effective to compute and implement.

Based on these conclusions, there is serious potential for a very significant contribution to the state-of-the-art in the development of a rational approach to structural design for high-performance vessels.

1.7 Project 05-9: Summary Review of Alternative Shipboard Powering Systems for Naval and Regulatory Review

Over the past few years CCDoTT has worked with a recognized nuclear power generating system supplier and a marine engineering/naval architect firm to ascertain both the technical and economic feasibility of a conceptual design shipboard power generation system, and the projected operational economics based on selected trade and cost assumptions. This project represents the final completion of the earlier programs and will correlate and consolidate the various technical and economic assessments into a persuasive and authoritative summary report of CCDoTT's prior studies that will be a precursor to military, commercial and regulatory interests and possible support for further development of the concept.

The project will identify those variables that have the largest impact on technical and economic feasibility of the concept

Once the variables are identified a sensitivity analysis will be conducted over a range established for each. The results will be assembled, based on the investigation above, into a coherent and readable summary report for submission to appropriate Governmental agencies and Maritime Industries potentially involved as described above.

The most recent and authoritative prior work published in this area was a multi-year effort managed by then JJMA (now Alion JJMA) that was terminated in 2003. Our review of this report concluded that this effort could not form a reasonable basis for this study for a number of reasons. Our review of other prior published work on the subject similarly revealed the absence of authoritative cost estimates for the propulsion system concepts employed.

Thus, it was necessary that the study team initiate its own conceptual design of a state-of-the-art nuclear propulsion system, and, because of the shortened planning horizon, we based our design on a Pressurized Water Reactor (PWR) system, a technology that has been well proven in 50 years of service in both the central station and marine propulsion applications. The concept designs developed in this report are believed to be feasible technically and to form the basis for authoritative and realistic cost estimates of the total ship systems considered for a future high speed service as compared with conventionally powered ships in current service.

The technical results of the study indicate that both high-speed nuclear powered ship alternatives are technically feasible and should perform creditably and safely in their respective services. Although the particular vessels selected as references for the concept studies were initially found to be limited in realizing the full advantages of the high powered nuclear propulsion and power system developed by Rolls-Royce Nuclear and DRS Technologies for this study, subsequent design analysis performed in the course of our study has concluded that the basic performance objectives as cited in Table 1 (page 62) are entirely achievable in both applications particularly when subjected to complete new ship designs capable of accommodating the high power characteristics required.

The dominant factor in the comparative fiscal equation will continue to be fuel costs – both nuclear and conventional fuel.

Although future oil prices are a paramount issue in the case of the commercial containership, the authors do not believe that such is necessarily the case with the Naval Auxiliary application that has been described in this study.

Where to go next has been discussed with CCDoTT, but many of the factors and assumptions discussed in the study still warrant further review.

1.8 Project 05-10: Feasibility Assessment of Short Sea Shipping to Service the Pacific Coast

CCDoTT has been involved with and supporting studies on Short Sea Shipping (SSS) since the late 1990s. Most early studies dealt with the East Coast and the I-95 Corridor. Most related to impact on trucking and associated highway traffic. Specific routes and ship designs have been considered to include high speed multihull ship designs on routes between CONUS and Bahamas. We became involved with the DoD Office of Force Transformation who was interested in studying dual use commercial and military high speed designs to expand US ship building through the use of composite technology. The current study was the first West Coast focused study specifically aimed at SSS.

The objective of the study was to demonstrate the preliminary market, economic, and technical feasibility of a commercial short sea service on the Pacific Coast that handles domestic and international (feeder) freight moving between major transportation hubs and population centers. The effort also addressed the potential emissions of SSS compared to traditional trucking and the military applications of short sea service and vessels including their scope for contributing to military deployment requirements. The overall approach was to apply commercial market requirements to determine the feasibility of short sea service along the Pacific Coast. Commercial requirements include costs and service standards (transit time, frequency, on-time reliability, etc.) that are competitive with today's modes (road and rail).

Cargo flows and trade lane analysis was conducted and 107 Business Economic Areas (BEAs) were determined that had at least minimal potential to be suitable for truck and rail cargo diversion into the coastwise service. Truck cargo was analyzed at the county level in the US. All counties within the states of California, Oregon and Washington were included, and the truck traffic data provided was split into three types, common carrier truckload and less-than-truckload (LTL), and private truckload.

Cargo diversion shipper surveys were conducted and 43% of the respondents indicated that they would consider using coastal shipping for north-south shipments along the West Coast. Diversion was dependent on price-transit time scenarios with significant variation between scenarios. Some variants are, port locations, north-south vs. south-north, speed of ships, time factors, fuel cost, ship costs, congestion, prevailing truck rates, etc.

This study was an initial study to be followed by a more detailed study based on the issues and direction indicated here. Additionally, the next study will look at the SSS business model and address roadblocks to adoption of SSS as an alternate mode.

CCDoTT

Center for the Commercial Deployment of Transportation Technologies

Agile Port and High Speed Ship Technologies

FY05 Final Summary Report
Vol. I - Projects 3-6 and 8-10

CCDoTT FY05 Project Summaries

Project 05-3: The Evaluation and Implementation Plan for Southern California Maglev Freight System

Author: **Dr. Kenneth James, Professor, Department of Computer Engineering and Computer Science, California State University, Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840**

Abstract: Recent cargo growth projections for the economic engine that is the Port of Los Angeles/Long Beach (LA/LB) have the container traffic tripling over the next 10 to 15 years. A majority of these containers will pass through the LA basin and on to the rest of the country. The port facility is approaching the maximum size and infrastructure capabilities of the harbor area. One concept to accommodate the anticipated growth in trade is an inland port such as the one proposed to be built in Victorville, CA. The site is well positioned due to its proximity to LA, the conversion of George AFB to the Southern California Logistics Airport, and immediate rail and highway access. However, the continental bound container traffic will increasingly clog the already stressed road and rail systems through the LA metropolitan area, and generate diesel pollutants beyond the already unacceptable levels. Efficiently moving this large volume of containers through the LA basin with minimum pollution and congestion is both a local and national concern.

Technical Objective:

With the origination of the Electric Cargo Conveyor (ECCO) concept by the CSULB College of Engineering through CCDoTT funding, two commercial embodiments for container transport—both with military application—have become apparent: (1) an immediate ECCO application for moving 5000+ containers per day between the Ports of LA/LB and the I-710 Corridor ICTFs, and (2) a longer term ECCO conveyor system capable of moving containers between the Ports of LA/LB and both the inland port warehouse concentrations and transcontinental rail terminals at Victorville and Beaumont.

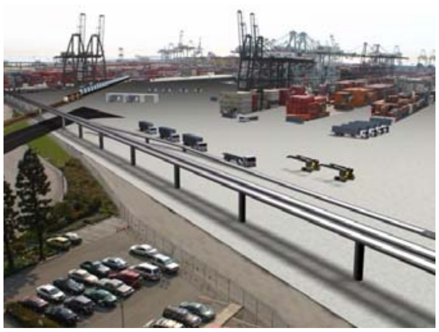
Technical Approach:

ECCO uses the proven, highly reliable passenger technology: magnetic levitation ("Maglev") applied to freight movement. One of CCDoTT's technology providers, General Atomics (GA) of San Diego, licenses the Lawrence Livermore Labs "Inductract" approach to both freight and passenger Maglev, and is the nation's leading developer of Maglev propulsion systems for the military. On June of 2006, CCDoTT and GA configured the *world's first* ECCO prototype (above photo) at GA's San Diego facility. Instead of wheels where a shipping container's entire weight is focused on a small contact area, the ECCO system uses a large area of permanent magnets under the carriage to distribute the container weight uniformly over the carriage and the underlying guideway. Thus, ECCO not only has the largest payload-to-carriage ratio of any land transport, but also—due to minimum stress on the guideway—is the most reliable and economical method to *elevate* freight transport!

In addition to eliminating wheels and their accompanying noise and vibration, ECCO further advances land transport by having its electric motor within the guideway, and not in each carriage. This Linear Synchronous Motor (LSM) powers only the short portion of the guideway where a container carriage is present thus assuring minimum energy use and maximum safety! Extra power for steep grades can be built into the guideway where needed, rather than augmenting on-board propulsion. Using stationary electrical power, ECCO produces no pollution along its path. ECCO's manpower and overhead costs are minimal in that the entire system is computer controlled and there are no moving parts to wear out. This results in lower, more cost effective life-cycle costs when compared to other systems. Finally, system security is insured not only by the containers being rapidly moving, unmanned, and elevated, but also the application of numerous optical-pattern-recognition cameras along the length of the system.

Mitigation Plans Are Not the Answer: While plans for replacing present day diesel trucks and locomotives with cleaner self-propelled systems is necessary (Port's "Clean Air Action Plan"), continued port growth will nullify any pollution reduction. The required mitigation expense does nothing for congestion and noise. As previously mentioned the ECCO system uses clean, stationary electrical sources. Delivering power through the electric grid also allows for application of renewable energy sources like wind and solar. Also, since the ECCO system has no moving parts or contact friction, particulates of rubber, asphalt and concrete are nonexistent. Diesel-powered road and rail systems require costly pollution mitigation approaches. The same money can build a better transport system which produces no pollution, is more reliable, and is less expensive to operate.

First Application and Cost of a Port ECCO System: A number of terminals at the San Pedro Ports do not have the capacity for moving directly by rail, all containers destined to pass through the LA basin and on to the rest of the country. Upwards of two (2) million containers must be drayed from those terminals to railheads between the Ports and downtown LA. The first application of the ECCO was defined in a 2006 contract from the Port of LA to GA (with CSULB's ECCO concepts supporting the system architecture) to be a preliminary cost estimate for an ECCO system between the Port and Intermodal Container Transfer Facilities (ICTFs) near the Port moving 5000+ containers per day. The team of CSULB, GA, and nationally recognized civil engineering and railroad signaling safety companies determined the cost of a totally elevated Port system to be $90M/mile. This is considerably less than a trenched rail corridor ($125M/mile) or new, at grade, freeway ($150M/mile) that can carry the same container volume but slash though the community and the environment. In addition, the operating cost of the port ECCO system is $2.20/container-mile; of which $1.00 is the cost of electricity. The present cost of trucking containers from the Port to the major ICTFs along the I-710 indicates the ECCO system's "fare box" has the potential not only to pay for its day-to-day operation but also its amortized capital costs.



As shown in the adjacent sketch, the ECCO is totally compatible with port operations. Being elevated—except when configured as an at-grade spur or siding—the ECCO does not impact rail or truck-gate operation. The system utilizes the same equipment and labor procedures that are presently used at terminals to load and unload near dock rail. However, to fully utilize the capacity of ECCO more automated equipment with computer managed container storage is required.

The Southern California Application: Existing clean and efficient passenger systems using Maglev technology already outperform road and rail passenger systems. The more recently developed ECCO technology can move containers out of the port to ICTFs, inland ports, and beyond more effectively than road and rail. The long term solution to port growth, congestion, and pollution is to complement existing as well as proposed road and rail expansion in Southern California with the ECCO system. Trucking containers from the Port to inland warehousing complexes, and cumbersome rail movement of containers through the LA basin to the origins of transcontinental rail at Victorville and Beaumont will then be minimized.

Project Summary:

Significant Results:

The prime result of this program was to bring awareness to the both the goods movement community and the environmental protection community that a technology exists that can satisfy both groups' objectives: ***increase port throughput while significantly reducing pollution.***

Specific results as described in the major deliverables of this project are as follows:

1) A detailed design and analysis for the immediate application of a Port of LA to ICTF ECCO system, demonstrating compatibility of maglev container transport with the port facility.

2) Applying and upgrading the CCDoTT Modeling Suite's Aggregate Port Model to demonstrate the competitive advantages of a maglev system over conventional container transport for the immediate ECCO application.

3) A study performed by Manalytics projecting the potential rates and capacity requirements for both the immediate and long term commercial maglev embodiments.

Next Steps:

Results indicate that Maglev technology in the form of the ECCO system is can be constructed and be operated as a container conveyor in the port environment. Initial economic feasible has also been demonstrated, however, a complete business plan modeling a specific customer application would likely generate angel funding from the State and Federal government in the amount of 40M$ to 60M$. This money would be used to construct a short demonstration project of about one mile in length that would produce actual cost and operational performance data. This data and its likely validation of the project's profit predictions will then encourage private financing for a full-scale application.

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Testimony to joint California Assembly and Senate Transportation and Infrastructure Committees (Sacramento) February, 2006

Peer Review Boards:

Transportation Research Board
July 10, 06 La Jolla, CA
Electric Cargo Conveyor (ECCO) System, Ken James, California State University at Long Beach

Highlight Presentations for FY05 (CY2006):

Feb 28-California Assembly and Senate Transportation and Infrastructure Committees (Sacramento)
March 23-President Alexander
March 24-Congressman Rohrabacher
April 21-Richard Powers, Ed Morales Gateway council of governments (405 & 710)
April 27-GA, Sandia National Laboratory Labs (San Diego)
April 27-Gateway City Council of Governments and+ 710 Project committee {Paramount City}
June 14-CCDoTT Washington presentation
June 19-Gateway City Council of Governments and 605/91 presentation

July 10-TRB Conference
Aug 29-George Cunningham (Cunningham Report)
December 13 Gov Schwarzenegger

Glossary of Acronyms:

CCDoTT - Center Commercial Deployment of Transportation Technologies
ECCO - Electric Cargo Conveyor
GA - General Atomics
ICTF - Intermodal Container Transfer Facility
LA/LB - Port of Los Angeles/Long Beach
LSM - Linear Synchronous Motor

Project 05-4: Automated Multidisciplinary Design Optimization for Multi-Hull Vessels

Author: Dr. Hamid Hefazi, Professor and Chair, Department of Mechanical and Aerospace Engineering, California State University, Long Beach, 1250 Bellflower Blvd, Long Beach, CA 90840

Abstract: This report summarizes the development of a synthesis level Multidisciplinary Design and Optimization (MDO) tool for multi-hull ships. The MDO tool is unique in utilizing advanced multiobjective optimization methods, neural networks, and in its broad scope, integrating powering, stability, seakeeping, structural optimization, cost and payload capacity into a single design tool. The method is a comprehensive and efficient way for the designers to analyze various requirements at the preliminary design stage. Multiobjective optimization results are presented in the form of Pareto optimum solutions, allowing the designer to select the optimum solution of interest. The method is applied to several multi-hull ship concepts. Detailed studies are conducted in order to determine the best approach for the application. Improvements to the neural network developments and optimization process are also presented. Details of various aspects of the MDO tool are described in four deliverable reports that have been submitted. Extension of the method to subsystem level is planed for the next phase of the program.

Technical Objective:

The overall objective of this project is to develop a multidisciplinary design and optimization method for use in the design of multi-hull ships. The MDO method is based on a Systems Engineering approach. Widely used in aerospace industry, Systems Engineering approach can be divided in three distinct phases. In the synthesis design phase the goal is to define the overall system architecture in terms of a limited number of (order of ten) design variables. In the subsystem design phase, the overall system architecture is used as input to define subsystems designs. The final stage of the System Engineering approach generally includes system evaluation and test and system build. In a complex design problem such as a multi-hull ship, many subsystems are multidisciplinary problems as well, thus the MDO methodology developed here can be applied at the system or subsystem level. Figure 1 from Reference [1] shows the system approach schematically.

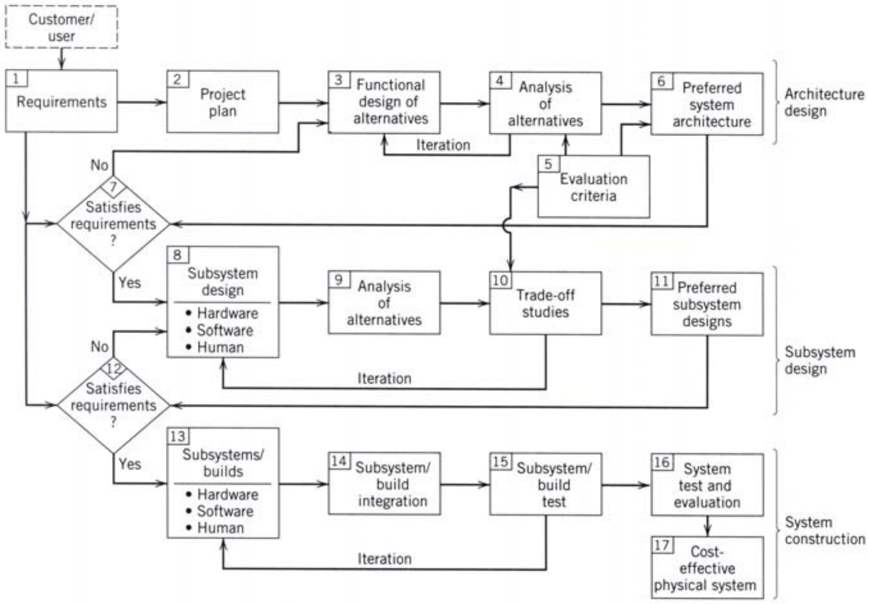

Figure 1.1. Overview of the systems approach.

Using advanced multiobjective optimization, our method will integrate powering, stability, seakeeping, hullforms optimization, structural optimization, payload and ship cost into a single design tool. Building upon progress made in the FY 04 program [2], the objective of the FY05 program was to enhance and finalize the synthesis level MDO tool and apply it to several practical applications of interest. Furthermore develop the subsystem models for seakeeping, and structural loads and hullforms optimization, for extension of the tool to subsystem design stage.

Technical Approach:

The MDO method consists of various “models” to evaluate powering, cost, stability, seakeeping, structural loads, etc. The outcomes of these models are then used by a multiobjective optimization method such as MOGA to perform optimization. The entire process is “managed” by iSIGHT [3], commercially available software designed for optimization applications. This process is schematically shown in Figure 2.

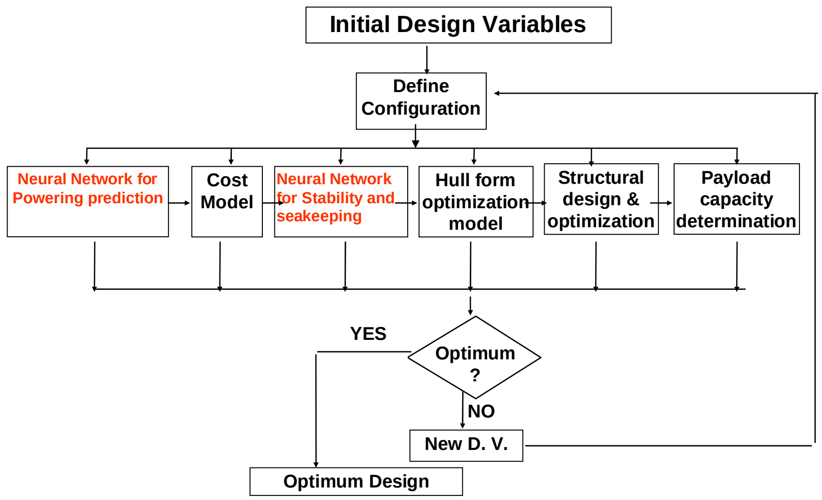

FIGURE 2: MDO APPROACH

Advances in computational science such as CFD and Finite Element analysis make it possible to evaluate the performances of multi-hull ships' subsystems (such as powering, seakeeping, structural weight etc) to some level of accuracy. However these analysis methods are too complex and computationally intensive to be of practical use to most designers, particularly at the early stages of the design process. Synthesis design tools therefore, rely on empirical or simplified approaches for performance analysis such as powering and seakeeping [4]. Our approach is unique in that it uses artificial neural networks for evaluating such subsystem performances. The methodology has been developed at CSULB and successfully applied to applications in shape optimization under previous CCDoTT program [5] .Another unique feature of our approach is its scope. Unlike other multi-hull MDO tools [4] which are limited to hydrodynamics (powering and seakeeping), our approach integrates powering, seakeeping; cost, hullfroms optimization, structural design and payload capacity all into a single design tool.

Project Summary:

The FY 05 program consisted of four tasks. The subsequent sections summarize accomplishments in each of these tasks. Separate deliverable reports with details have been submitted for each of the fours tasks.

Synthesis Level MDO Tool Development:

This task included the development of the synthesis model process and various design relationships for calculating areas, volumes, sizes, weights, stability and costs of multi-hull (trimaran) ships. These relationships are based on many technical literature sources and practical design experiences. Following the FY 04 work, during the FY 05 program, they were extensively revised and enhanced to be consistent with Navy's USCG, ABS regulations, and operational requirements for specific planned applications. They consist of more than 1800 equations organized in various Excel spreadsheets. Synthesis Design Model, in short, achieves a weight -

buoyancy, and required - available area/volume balanced design, with required propulsion and auxiliary machinery and with a check on stability. Details of the synthesis design models are presented in Task 4.1 and Task 4.3 deliverable reports. The flow chart in Figure 3 shows the synthesis model process.

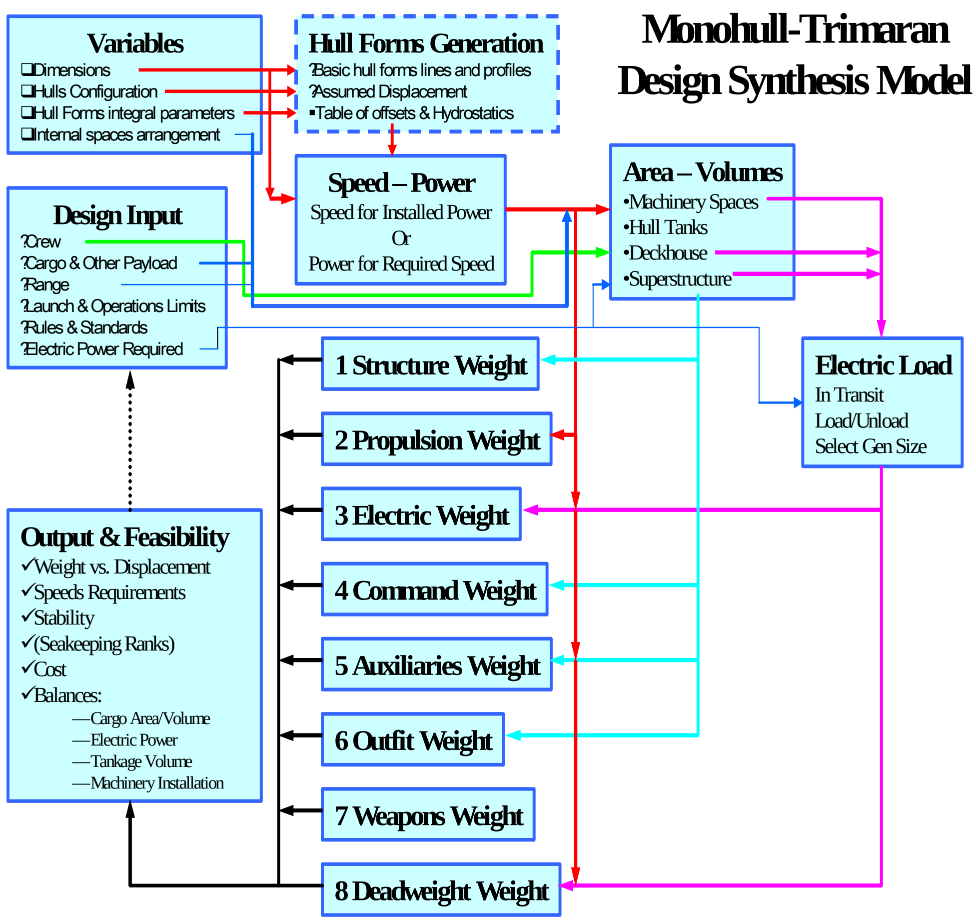

FIGURE 3: SYNTHESIS MODEL PROCESS.

The overall MDO method includes the following calculations:

- Speed-power and endurance fuel calculations.
- Area/volume calculations including:
  - o Required length, height and volume for machinery spaces for required propulsion plant and auxiliary machinery.
  - o Required tankage volume for required endurance fuel.
  - o Determines remaining hull area/volume available for payload items.
  - o Sizes superstructure and deckhouse above the main deck to exactly provide area/volume for the remainder of required payload and crew.
- Electric load calculations.
- Weight and center of gravity calculations.
- Required vs. available GM per USCG windheel criteria.

- Cost model.
- Seakeeping and structural loads

Throughout the optimization loop, the powering (Coefficient of Residual Resistance) is evaluated with a neural network trained as a response surface method, using the Cascade Correlation Algorithm. The neural network approach encompasses three steps:

1. Generation of the Training Set (TS) & Validation Set (VS).
2. Neural Network training to obtain a NN "evaluator(s)".
3. Optimization with NN evaluator(s).

A training set (TS) corresponds to a set of known data points (design variables and their associated values, such as objective function(s) and constraints) used to train the NN, i.e. the network attempts to achieve an output, which matches the input (training set). A validation set (VS) is a set which, unlike the TS, is not used for training per se, but rather is used for stopping the training. The purpose of the VS is to avoid over fitting which can occur with cascade correlation. Details of NN approach and its applications in the MDO process are presented in Task 4.4 deliverable report. A similar approach for inclusion of seakeeping in the method is developed under the FY 05 program which is summarized in the next section. Details are presented in Task 4.2 deliverable reports.

<u>MDO subsystem development:</u>

Work conducted under this task included the development of nomenclature for seakeeping, the definition of criteria, constraints, and approach for seakeeping performance, and structural loads assessment of multi-hull ships, and integration of seakeeping into multi-hull MDO tool. Similar to evaluation of powering, neural networks were used for inclusion of seakeeping in the MDO process. Once again, the process encompasses three steps.

1. Generating seakeeping and structural loads training set (TS) data using CFD,
2. Training neural networks (NN) for seakeeping subsystem MDO,
3. Integrating the trained neural networks in the MDO process.

The CFD program WASIM was used to generate the seakeeping training set (TS) data. WASIM program solves the fully 3-dimensional radiation/diffraction hydrodynamic problem by a Rankine panel method. For these methods panel models are required for both the hull and the free surface. A typical panel model that is used for generating the seakeeping data is shown in Figure 4

To generate the training set data, sixteen ship responses were evaluated using WASIM code. They include roll, pitch, vertical and transverse accelerations, bending moment, shear force, propeller emergence, etc. These responses are evaluated at sea states 4, 5, 6 and 7, three speeds of 15, 25 and 35 knots and 5 headings of 0, 45, 90,135 and 180 degrees. Hull configurations consist of the following variations:

- stagger of side hulls 0.00, 0.24, 0.40 & 0.80
- separation of side hulls 0.36, 0.75, 1.25
- overall vessel size 150m, 200m, 250m & 300m

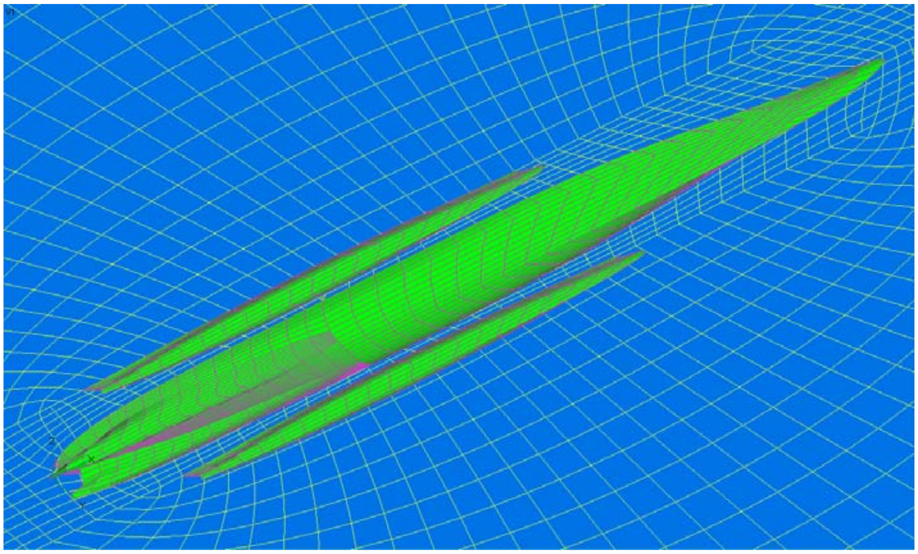

FIGURE 4: TRIMARAN PANELING FOR WASIM

The ranges of these parameters were selected based on the initial results, and in order to avoid studying options that were undesirable or unreasonable. These configurations represent 60 hull variations at 48 environments and 16 Criteria leading to a total of 46,080 data points for the training set.

Two approaches were studied for the integration of the seakeeping in the MDO process. The first approach is based on computing a seakeeping index as described in reference [6]. This "seakeeping index" can then be minimized as one of the objective functions in the multiobjective optimization process. The second approach is the direct imposition of seakeeping constrains based on some acceptable transit motion criteria. The motion and seakeeping criteria for the vessel while under transit conditions have been derived from the seakeeping criteria for the transit and patrol mission for a NATO Generic Frigate [7]. The limits for the transit condition are listed in Table 1 as single amplitude RMS values of roll motion; pitch motion, vertical and lateral acceleration, bottom slamming and propeller emergence.

Parameter	Limit Value
Roll Angle	4.0 deg
Pitch Angle	1.5 deg
Vertical Acceleration	0.2 g
Lateral Acceleration	0.1 g
Bottom Slamming Index	20 per hour
Propeller Emergence Index	90 per hour

TABLE 1– TRANSIT CRITERIA

The roll angle criterion for the transit condition is independent of the roll period. The pitch angle criterion is independent from the pitch period of the vessel.

While imposition of all constraints for all environmental conditions (speed, sea state and headings for a given configuration is impractical, selected representative constraints can be imposed. As an example, in our application, eleven criteria were retained; Roll <4 deg. (for SS6, all speeds and 45, 90 and 135 deg, and Vertical Acceleration @ Stern Centerline<1.962m/s2 for SS7, 15 knots, 0 & 180 deg. Eleven neural networks corresponding to these criteria were trained and the outputs were combined into a MATLAB program which gives the eleven constraints for each combination of ship length, stagger and separation during the MDO process. Details of the method are presented in the Task 4.2 deliverable report. Some results are presented in Task 4.3 deliverable report. Using other constraints and using the seakeeping index approach is planed as part of the next phase of the work.

Application:

In this task, the MDO method was applied to three different design requirements of interest. Several single and multiobjective optimizations with and without seakeeping constraints, have been performed. A very detailed study has been conducted in order to determine the best approach for application of the method. Results of this section indicate that a careful optimization process, including selections of proper algorithms and proper initial population, have to be followed in order to obtain complete and meaningful results. This process and results are described in detail in Task 4.3 deliverable report. A sample case is summarized here.

The application of the synthesis level MDO tool consists of

- Definition of the design space, constraints and measure(s) of merit
- Running the MDO program to search the multi-dimensional design space using single or multiobjective optimization algorithms
- Construction of feasible and Pareto optimum solution sets
- Subsystem requirement definition corresponding to optimum measure(s) of merit.

Applications in this work are based on different High Speed Sealift Ship (HSS) concepts such as basic Army and USMC requirements for JHSS concept, and High Speed Connector (HSC) concept such as basic JHSV. For high speed sealift applications, multicriteria optimization is generally necessary. More specifically, Lift-to-Drag, LWT-to-Displacement and Cost are considered as objective functions. Furthermore, each requirement has its distinct constraints which are generally derived form mission requirements. Their purpose is to avoid exploring unreasonable designs.

The schematic of a generic trimaran configuration considered, is given in Figure 5. For synthesis level models, the specifics of the hull forms are not important, since all models (Stability, seakeeping, structural load, powering, weight, etc) are considered independent of hullforms. Configuration (spacing and stagger) however are considered as design variables. Incorporation of a parametric, non-dimensional offset representation of the ship hulls in the MDO along with means to transform offsets for variations in block and midship coefficients, center of buoyancy, widths and depth of transom length, area of bulb, etc. are planned for the next extension of this work.

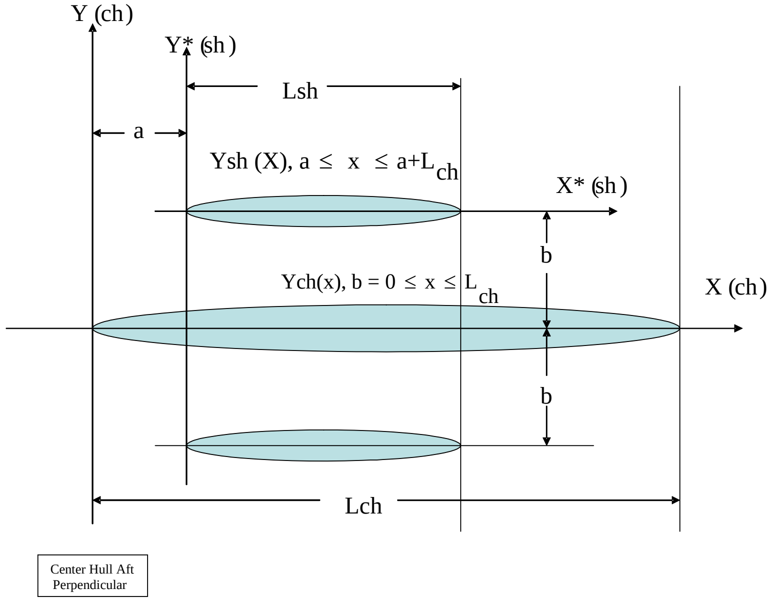

FIGURE 5: TRIMARAN CONFIGURATION (TOP VIEW)

The group of Design Variables defines the Trimaran geometry. This group includes the major hull dimensions and coefficients, basic configuration features and dimensional constraints. Since the hull dimensions include the draft this input establishes an assumed ship displacement with which to begin analysis. The configuration options include flooding standard (one or two compartment) which will control transverse bulkhead spacing and choice of freeboard deck (main or second deck) which will affect the stability analysis and extent of tankage. The dimensional constraints include both operational and building/launching considerations.

The example cases reported here is based on a High Speed Sealift (HSS) concept similar to the Army requirements of JHSS. Table 2 shows the design variables and their prescribed range. Table 3 shows other constraints that are imposed on the optimization process.

Design Variables	Lower Bounds	Upper Bounds	Description
Lch	800	1000	Length on Waterline Center Hull
Bch	70	80	Beam Center Hull
Dch	40	55	Depth Center Hull
Tch	20	30	Draft Center Hull
Cbch	0.45	0.70	Block Coefficient Center Hull
Cmch	0.66	0.80	Max Section Coefficient Center Hull
Lsh	200	300	Length on Waterline Side Hulls
Bsh	10	15	Beam Side Hulls
Dsh	30	55	Depth Side Hulls
Cbsh	0.45	0.70	Block Coefficient Side Hulls
Cmsh	0.66	0.8	Max Section Coefficient Side Hulls
Alpha	0.75	2.0	Separation
Beta	0	0.85	Stagger

TABLE 2: DESIGN VARIABLES FOR HSS

Constraints	Lower Bounds	Upper Bounds	Description
Tsh	3	30	Draft of Side Hull
Cwtdispl	-300	300	Calculated Weight – Assumed Displacement
Inrepower	-10000	100000	Installed – Required Power
Chfb	15	30	Center Hull Freeboard

TABLE 3: CONSTRAINTS FOR HSS

Here the center hull freeboard (chfb) is the difference between Depth of center hull (Dch) and Draft of center hull (Tch), “inrepower” is the difference between installed power and required power. Installed power is the amount of power generated by ship using advanced water jet propulsion for gas turbines as per the specifications to power generation.

The two objective functions for this case are to minimize the Lightship to Displacement Ratio (Wlsoverd) and to maximize the Lift over Drag (Loverd). Several optimization cases were run. Single objective optimization Sequential Quadratic Programming (NLPQL) and Multi-Island Genetic Algorithm (MIGA) were run for each objective (Lightship to displacement ratio and Lift over Drag). Multiobjective Genetic Algorithm (MOGA) which is a global search method was run using the Neighborhood Cultivation Genetic Algorithm (NCGA). Figure 6 below shows the results of single objective cases (max L/D and min Wls/D) and the distribution of the Pareto optimum solutions between the (two) single objective optimized solutions. It also shows the distribution of the 369 specified initialization points

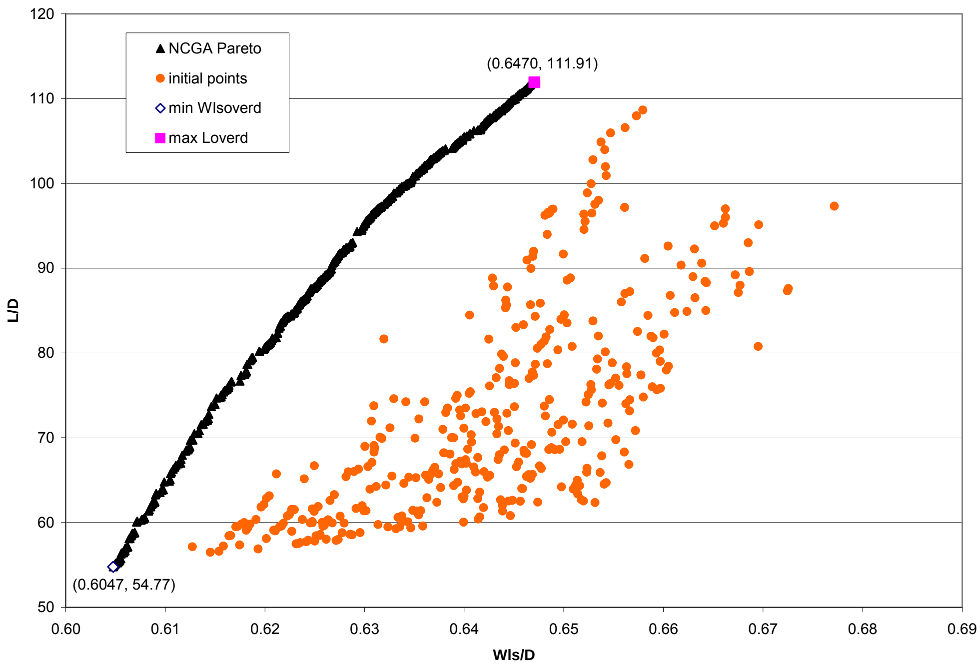

FIGURE 6: OPTIMIZATION RESULTS (WLS/D VS L/D) FOR NCGA WITH 369 INITIAL POINTS

Close examination of the (500) Pareto optimum solutions indicate that they fall within approximately 30 distinct “ship categories” were the length of the center hull (Lch) is the main driving parameter. It is noteworthy that while the Lch range was designated from 800 to 1000 feet, Lch values in the Pareto set range from 935 feet to 1000 feet. No Pareto points were found for values of Lch ranging from 800 feet to 935 feet.

This case was repeated with inclusion of the above mentioned seakeeping constraints. Furthermore, two other cases have also been studied in detail. They are based on USMC requirement of JHSS (referred to as JHSS light) and a High Speed Intra Theater Ship concept similar to JHSV. Detailed of these cases and analyses of results are presented in the Task 4.3 deliverable report submitted.

<u>Improvement of Neural Networks for Numerical Optimization:</u>

The work conducted under this task consists of a comprehensive study of artificial neural networks for application in the numerical optimization process, as well as improvements to our previous neural network development.

The modern approach used in the design of a complex system (the ship or component inside the ship) usually includes at some level an optimization as shown in Figure 7. In practical cases, the *design tool* may either be an optimization or design-of-experiment software, or a set of test cases identified by an experienced designer interested in conducting trade studies. The analyses performed at each subsystem level rely, in general, on a combination of semi-analytical models, advanced numerical methods such CFD and finite element analysis, and use of existing databases. Such optimization or trade study usually has to be able to handle a large number of design variables (say up to 30 or more) and explore the entire design space

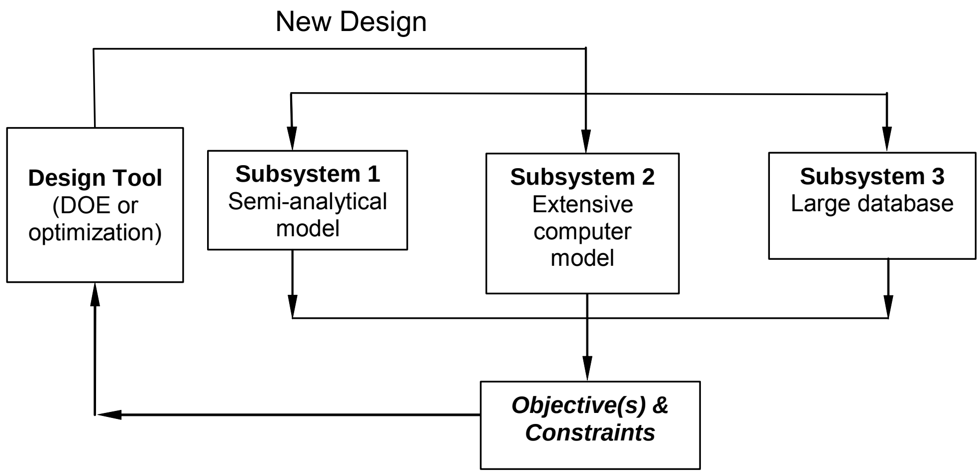

FIGURE 7: GENERIC SYSTEM DESIGN LOOP

Building upon several previous successful applications, our optimization process utilizes a neural network-based Response Surface Method for reducing the cost of computer intensive optimizations for applications in ship design. Complex or costly subsystems analyses are replaced by neural networks which are used to estimate the value of the function(s) of interest. The cost of the optimization is thus shifted to the generation of (smaller) data sets used for training the network. In some applications these data may already exist.

The focus of our work is on the use and analysis of constructive networks, as opposed to networks of fixed sizes, for treating problems with a large number of variables, say around 30. The advantages offered by constructive networks have led us to the selection of the Cascade Correlation algorithm. This topology allows for efficient neural network determination when dealing with function representation over large design spaces without requiring prior experience from the user. During training, the network grows until the error on a small set (validation set), different from that used in the training (training set), starts to increase.

In our study, the method was validated for a mathematical function for dimensions ranging from 5 to 30 and the importance of analyzing the error on a set other than the training set is emphasized. Improvements to the algorithm used the method of Ensemble Averaging, which consists of using an ensemble of networks to approximate the function instead of a single network. Ensemble averaging results show an average error 40% lower and a standard deviation 51.5% lower than the single best network. An example is shown in Figure 8.

Details of these developments are described in deliverable report for Task 4.4 as well as a paper submitted to the Journal of Ship Research for publication.

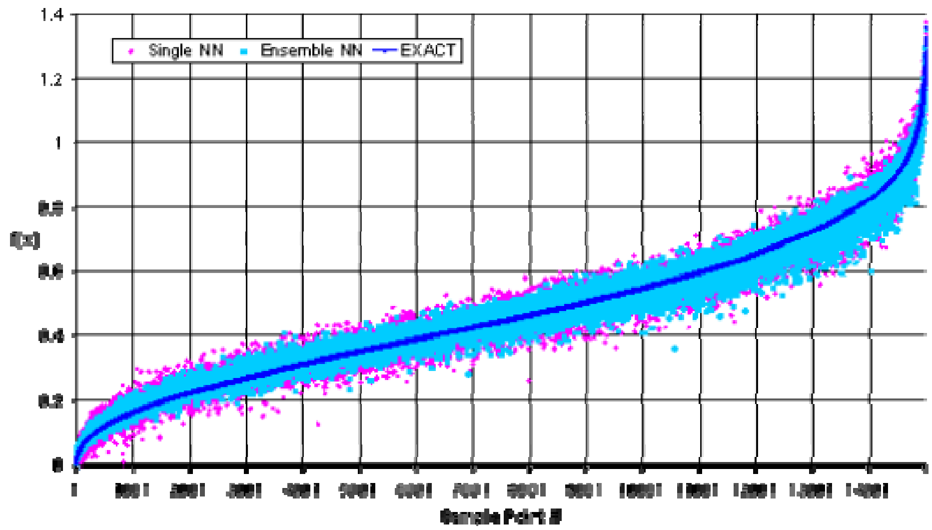

FIGURE 8: COMPARISON OF NN VALUES BETWEEN THE ENSEMBLE NETWORK AND THE "BEST OUT OF TEN" NETWORK.

Conclusion and Significant Results:

This program has developed a synthesis level MDO design tool for multi-hull (trimaran) ships. The tool is unique in application of advanced multiopbjective optimization methods, neural networks and in its broad scope, integrating powering, stability, seakeeping, structural optimization, cost and payload capacity into a single design tool. The method is an efficient way for the designers to analyze various high speed ship concepts at the preliminary design stage. Extension of the method to included hullforms optimization, more detailed seakeeping and structural loads assessments, and structural optimization are planed for the next phase of the project.

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Glossary of Acronyms:

ABS - American Bureau of Shipping
CFD - Computational Fluid Dynamics
HSS - High Speed Sealift Ship
JHSS - Joint High Speed Sealift Ship
JHSV - Joint High Speed Vessel
LWT – Light Weight
MDO - Multidisciplinary Design and Optimization
MOGA – Multiobjective Genetic Algorithm
MIGA – Multi-island Genetic Algorithm
NN- Neural Network
NLPQL - Sequential Quadratic Programming
NCGA – Neighborhood Cultivation Genetic Algorithm
TS – Training Set
VS – Validation Set
USCG – US Coast Guard
USMC- US Marine Corp

Project 05-5: Waterjet Self-Propulsion Model Test for Application to a High-Speed Sealift Ship

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Abstract: Waterjets are of interest for many reasons for high-speed ship applications. The waterjet inlet will draw flow from the ship boundary layer region, which lowers the inlet momentum velocity of flow into the waterjet inlet to values below the ship speed. This lower momentum inlet flow improves the waterjet propulsive efficiency by recovering energy that would have been lost in the hull boundary layer. Waterjet flush inlets have very low drag impact on a ship, and for high-speed ship applications reducing drag is critical. Past model hull tests have indicated that negative thrust deduction factors are possible with waterjet propulsion systems installed[1]. Negative thrust deductions would be very desirable for high-speed shipping since this would mean that the waterjet system is actually lowering the drag of the ship compared to the baseline bare hull drag of the same ship, which illustrates the importance of waterjet propulsion system development. For comparison, typical propeller systems are always associated with positive thrust deduction factors meaning that the propulsion system has drag associated with it that requires additional powering to overcome relative to the bare hull drag.

CCDoTT has supported a multi-phase effort to develop a large axial-flow waterjet design for application to high-speed shipping. Commercially available large waterjets have been based on mixed-flow pump designs, which result in a much heavier and wider waterjet system than an axial-flow waterjet system. Axial waterjet units have a 15-20 percent weight advantage over comparable mixed-flow designs because of their straight-through flow design does not require any radial growth that adds significant weigh to the mixed flow type pumps. Weight is a critical item on high-speed ships; therefore, the benefit of a much lighter axial waterjet system is obvious for high-speed ships. Since high-speed ships favors narrow hulls with high length-to-beam ratios, there is a problem having enough transom width to install the requisite number of waterjet units to absorb the significant amounts of power that can be required for high speed. If the transom must be widened to accommodate the waterjets, increased transom drag will result. The CCDoTT axial waterjet design is significantly narrower than a comparable mixed-flow design, and generally three axial waterjets can fit in the same transom width that could only accommodate two comparable mixed-flow waterjets. The need for axial-flow waterjets is evident, and this phase of the CCDoTT effort looks at the sizing and performance impact of applying the CCDoTT axial waterjet design to a representative high-speed hull.

There is a significant interest in commercial and military applications for high-speed craft, and these types of craft have all favored waterjets for propulsion. At present, catamaran hulls have seen significant commercial interest for high-speed applications, and the military has been operationally evaluating catamarans of significant size and speed for their potential future applications. For these reasons, it was deemed appropriate to perform the model self-propulsion testing using a representative high-speed catamaran hull model with scaled operating waterjet inlets, as this would have the most immediate interest.

Technical Objective:

The overall self-propulsion test objective is to completely define the hydrodynamic performance characteristics of the CCDoTT advanced-design axial-flow waterjet propulsor as installed in a suitable high-speed craft. The aim of the self-propulsion model tests was to take sufficient data to determine the inlet-hull interactions and develop thrust deduction factors from the model data, which also required that hull boundary layer data be obtained. All this information would then be used for extrapolation to the full-scale ship. Separate water tunnel testing of a larger-scale CCDoTT axial pump model were performed under an earlier phase of CCDoTT work[2] to adequately define critical powering characteristics and cavitation limits of the CCDoTT axial waterjet pump design. Therefore, for self-propelled waterjet model testing, model pumps only need to produce the required flow rate with reasonably representative jet energy and momentum characteristics. The extrapolated data obtained in both water tunnel tests of the pump and the towed self-propulsion hull model tests then constitutes a complete data set characterizing the overall performance of the combined hull and propulsor. This information would then be sufficient to determine the full-scale axial waterjet sizing and performance conditions in the representative catamaran hull.

Technical Approach:

Self-propulsion model testing of a single catamaran demi-hull with a pair of operating scaled waterjet inlets was undertaken. The baseline hull was a representative 40-knot catamaran design, but only a single hull was tested since the main area of interest was the inlet-hull interactions. At design speed, the drag effects of the catamaran hulls on each other tend to be at a minimum, and the use of a single hull greatly reduced the cost and complexity of the testing. Testing was performed at the Naval Surface Warfare Center, Carderock Division, on Towing Tank Carriage No 1. Sufficient test data was required to cover the range of operating conditions anticipated for a selected full-scale waterjet propulsion installation. The 17.5 to 1 scale self-propulsion model of a single catamaran demi-hull was tested to determine powering characteristics at design and off-design operating conditions. The model size built was 19.8 feet long, which is of sufficient size to provide accurate data based on the experience of the towing tank engineers. The model included operating scaled waterjet inlets with representative waterjet pumps. For the self-propulsion testing, it is important that waterjet inlet be properly scaled and operates at the scaled flow rates so that the inlet-hull interactions are modeled for their effects on overall propulsive performance. The waterjet pumps are not specifically modeled since the Froude-scaled testing conditions prevent pump model operation at cavitation and Reynolds numbers that can approximate full-scale values for these critical parameters. Representative pumps with thicker blade sections are acceptable since pump performance measurements are not critical. Rapid prototyping was used to fabricate accurately scaled waterjet inlets and representative waterjet pumps, with the waterjet arrangement and fabricated parts shown in Figure 1. The necessary waterjet pump performance data for extrapolation was obtained from the earlier water tunnel performance tests of a larger scale model of the CCDoTT axial flow waterjet pump[2].

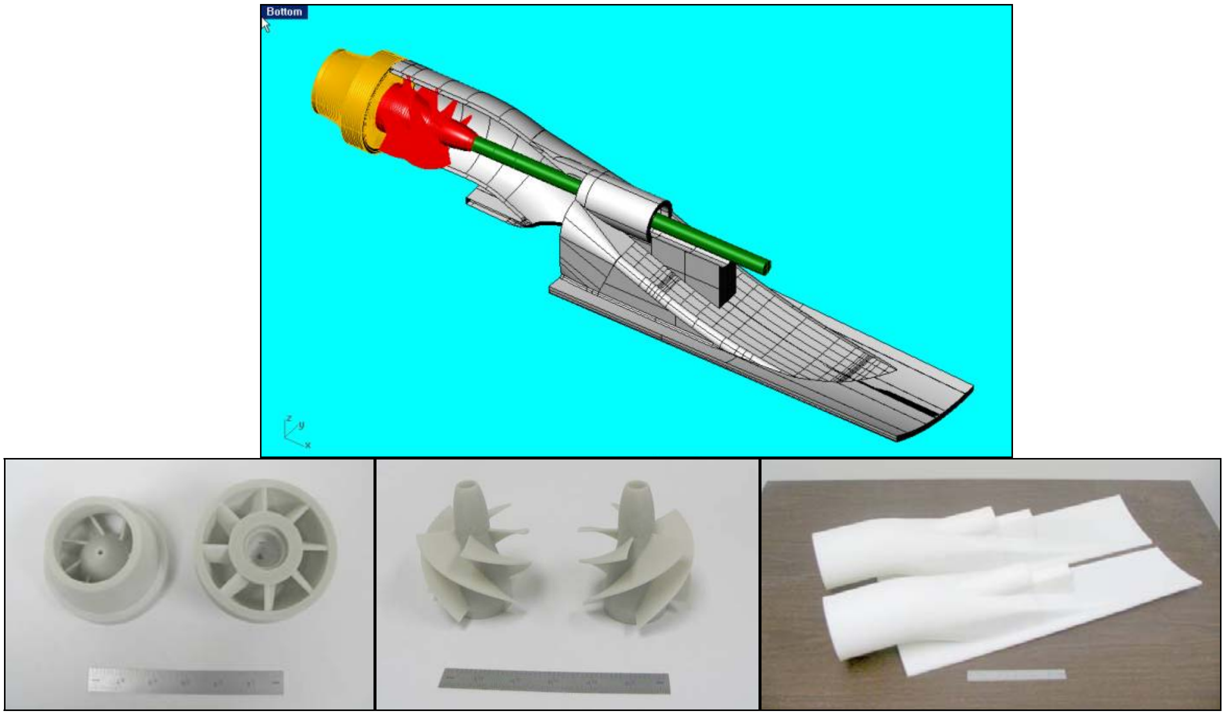

FIGURE 1 - WATERJET ARRANGEMENT AND THE RAPID PROTOTYPING COMPONENTS FOR THE MODEL

The catamaran model hull was laid up and constructed in a mold from fiberglass layers. The hull was built in halves and then joined along its length to form the complete hull. The two rapid prototype waterjet inlets were fabricated and include a small portion of the hull that surrounds the inlets. The inlets were attached in the hull mold and the model hull was constructed around the inlets to incorporate them as part of the model hull. The hull is symmetrical about the hull centerline so that everything forward of the waterjet inlets would be the same, but mirror-imaged about the hull centerline as were the pair of waterjet inlets at the stern. Using two pumps with opposite rotation to each other then represented a mirroring of the pumps about the hull centerline. Since the model tests were conducted in a straight-ahead condition, both pumps should have identical performance. This allowed for full instrumentation and measurements on one pump to be indicative of what was happening on the other pump, with some measurements taken on the second pump to assure consistency.

Testing procedures began with the tow tank testing of the bare hull model. The bare hull is the model hull without the propulsion system affecting the external flow around the hull in any manner. In this way, when the model hull is tested with the complete operating propulsor during the self-propulsion runs, the impact of the propulsion system on the hull performance can be gauged against the bare hull as a baseline. For the present catamaran model, the waterjet inlets were incorporated into the hull model during model fabrication. For the bare hull runs, inserts were fabricated to cover the inlets and taped in place over the inlet openings to bring the model hull to a bare hull condition. The inlet cover was removed for later self-propulsion testing. For all the tests, the model was free to heave and pitch, but was restrained in yaw and roll. During self-propulsion runs where the waterjet will be operating, the ingestion of portions of the model hull boundary layer by the waterjet inlets will impact the waterjet performance, and information on the boundary layer needs to be obtained. As part of the bare hull runs, boundary layer traverses were made one inlet diameter upstream of the corners of the port side inlet location with a pair of pitot-static probes.

FIGURE 2 - MODEL HULL WITH WATERJETS ON THE DTMB TOWING CARRIAGE

Project Summary:

Significant Results:

The model test results indicated that for a 40-knot ship design point, the ship waterjets would have an inlet wake fraction of $w_S = 0.0966$ while operating at a jet velocity ratio, JVR, of about 1.55 with a flow rate of 801.74 cubic feet per second per pump. The inlet wake fraction of $w_S = 0.0966$ shows that the inlet momentum velocity, due to boundary layer ingestion at the design point, is almost 10-percent below the 40-knot ship speed and this allows about 8-percent additional thrust performance or power savings compared to an inlet momentum velocity equal to the ship speed. The total design point required net thrust for both waterjets from the scaled self-propulsion tests was $T_{NET} = 139{,}313$ pounds force, while the scaled ship bare hull total resistance was $Rt_S = 145{,}595$ pounds force. This resulted in a 40-knot design point ship thrust deduction factor of $t_S = -0.0451$. The ship thrust deduction factor was negative for ship speeds in the 25 to 45-knot range, and was at its minimum in the 40-knot design point speed region, as shown in Figure 3. Negative thrust deduction factors are significant as they indicate that the presence of the waterjet system helps reduce drag compared to the baseline bare hull ship drag. Negative thrust deductions are all but unheard of for typical propeller-driven ships. The waterjet system, with its low-drag flush inlet and its favorable influence on the hull pressures and flows, will be very important for enhancing high-speed ship applications.

The CCDoTT axial waterjet pump was evaluated for its sizing and performance in this representative high-speed catamaran hull application. A model of the CCDoTT axial waterjet pump had been tested separately in the water tunnel at NSWCCD to establish its hydraulic and cavitation performance characteristics[1]. Combining the water tunnel pump results with the scaled model hull results will establish the sizing and performance of a CCDoTT axial waterjet installation. The water tunnel tests established the design point head and flow coefficients for the CCDoTT axial pump design and indicated a pump hydraulic efficiency of no less than 91.8 percent. This information enables the axial waterjets to be scaled to any craft speed and power application of interest using programming that accounts for the other waterjet system considerations such as inlet losses. The present representative ship design was based on having 12,069 horsepower available for each waterjet at the 40-knot design speed. The resulting CCDoTT axial waterjet for this application had an inlet and impeller diameter of 57.95 inches, about 2-percent smaller than the proposed craft waterjet system, and operated at 507.3 RPM to produce the required net thrust at 40 knots from a flow rate of Q_S = 801.74 cubic feet per second per pump and a jet velocity ratio of JVR = 1.55. The propulsive efficiency for the CCDoTT axial waterjet installation with this ship would be 70.85 percent. The axial waterjets have a suction specific speed of N_{SSS} = 10,991 at the 40-knot design point speed, which is at least 15 percent below their cavitation inception value from the water tunnel testing. Off-design predictions showed that with only one axial waterjet operating instead of the two, the single axial waterjet could still absorb full power with N_{SSS} of less than 14,000, while exceeding the N_{SSS} range of 14,500 would increase the likelihood of cavitation breakdown based upon the water tunnel test results[2].

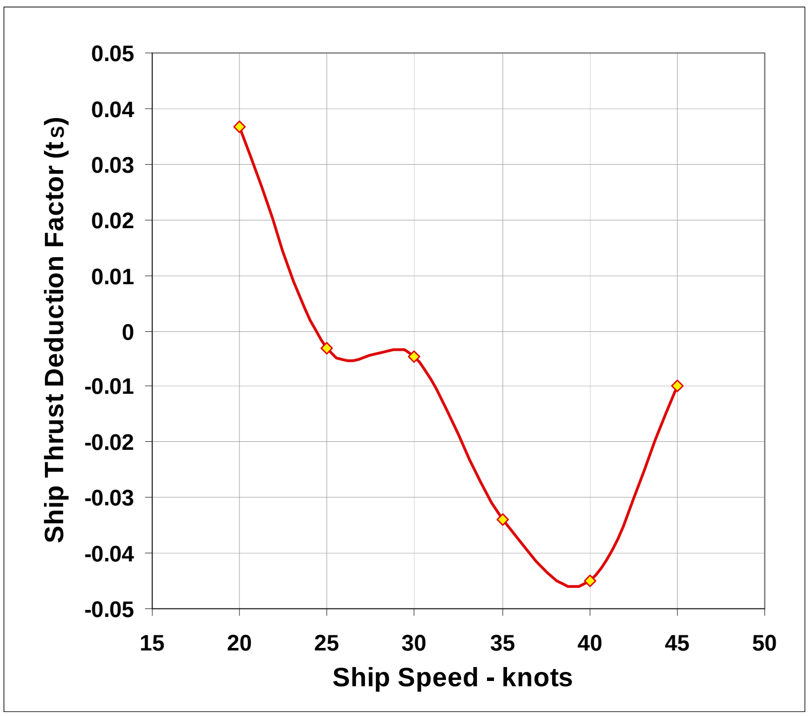

FIGURE 3. WATERJET SHIP THRUST DEDUCTION FACTORS AS A FUNCTION OF SHIP SPEED

Axial waterjet units have a 15-20 percent weight advantage over comparable mixed-flow designs because of their straight-through flow design, which does not require any radial growth that adds weight. Also, this gives axial waterjets a narrower installation width, which allows more units to be installed in the limited transom widths favored for high-speed craft. In addition, the inlet diameter of the CCDoTT axial design is about 2 percent smaller than proposed alternative waterjets for this application, which were based on mixed-flow pump designs rather than the more compact axial-flow design. The smaller inlet diameter requirements of the axial-flow design also save additional system weight since weight varies as approximately the cube of diameter, and even small reductions in diameter can provide meaningful weight savings, especially on large, high-powered waterjets.

Next Steps:

The waterjet inlet is the interface between the waterjet pump and the external hull flow and is in need of further understanding, since its arrangements and design can have a big impact on high-speed shipping. Waterjet inlet losses affect the waterjet system performance and powering, while keeping inlets size and volume requirements to a minimum will save important space and weight but need to be considered with respect to impacts on inlet performance. An isolated waterjet inlet will perform differently than the same inlet mounted side-by-side with other similar waterjet inlets. The self-propulsion tests showed that at bollard there was a small circulation set up in the waterjet inlets. Inlet circulation can benefit the pump loading if the pump is installed so that its rotation direction is opposite the circulation. It is likely that some inlet circulation occurs while underway that needs to be established for different arrangement cases to have the pump installed with a beneficial direction of rotation. The waterjet self-propulsion model test performed for CCDoTT showed that negative thrust deductions can occur for a high-speed waterjet propelled craft. This means that the overall operating waterjet system was acting in a way that it helps to lower the drag on the high-speed craft below its baseline bare hull drag. Continuing efforts to better understand how the operating waterjet inlets can reduce drag will only result in further enhancements for high-speed shipping beyond the benefits that the development of the more compact and lighter weight axial flow waterjets will help bring to high speed shipping.

Since it does not protrude or basically interfere with the flow around the hull and would be expected to have a relatively low drag impact, the flush type waterjet inlet would be the logical waterjet inlet of choice for high-speed shipping. The operating flush inlet will draw flow from forward of the inlet and primarily from the region adjacent to the hull. Flow near the hull includes the hull boundary layer flow, and ingestion of boundary layer flow by the waterjet inlet will result in a lowering of the inlet momentum velocity to the waterjet inlet to values below the ship speed. This improves the propulsive efficiency of the waterjet system as the waterjet system benefits by recovering the energy from the hull boundary layer wake that would normally be lost. However, the waterjet inlets are located far aft on a ship and the removal of portions of the hull boundary layer by the waterjet inlets would not seem to account for much real reduction in overall hull frictional drag and would not seem a likely explanation for the negative thrust deductions that were determine in the self-propulsion testing.

The operating waterjet inlets do affect the flows and pressures on and around the aft portion of the hull. Pressure tap data from the self-propulsion hull model tests clearly showed areas of increased pressure on the hull along side and aft of the operating waterjet inlets. Regions of higher pressure on the aft hull bottom as shown in Figure 4 would be expected to generate lift on the hull and benefit drag with reduced trim by decreasing the aft hull sinkage. However, the trim and aft sinkage data for the self-propulsion model showed slight increases in both with the waterjets operating, as shown in Figure 5 which compares the trim and fore and aft sinkage or rise data for the bare hull (BH) with the self-propulsion (SP) runs, and this would seem contrary to getting negative thrust deductions.

The waterjet inlet is part of the waterjet system and serves as the interface between the waterjet pump and the external hull flow and its proper design and arrangement implications need to be investigated, as they will affect the overall waterjet system and thus the craft performance. There is a lot more happening in and around the waterjet inlet that needs to be understood as the operating inlets have been shown to affect the pressures and flow fields around the aft hull. How the operating waterjet inlets reduce the craft drag to values below the bare hull drags to provide negative thrust deductions for a high-speed ship application is not clear and needs to be studied to understand its additional potential for high-speed shipping application. Systematic CFD analysis of operating hull mounted waterjet inlets of different design, installation, and arrangement should provide most of the answers for best understanding of waterjet inlets and their beneficial impacts for high-speed shipping and would be a recommended next direction to further build on the benefits of axial flow waterjet technology that have been developed and demonstrated under CCDoTT sponsorship.

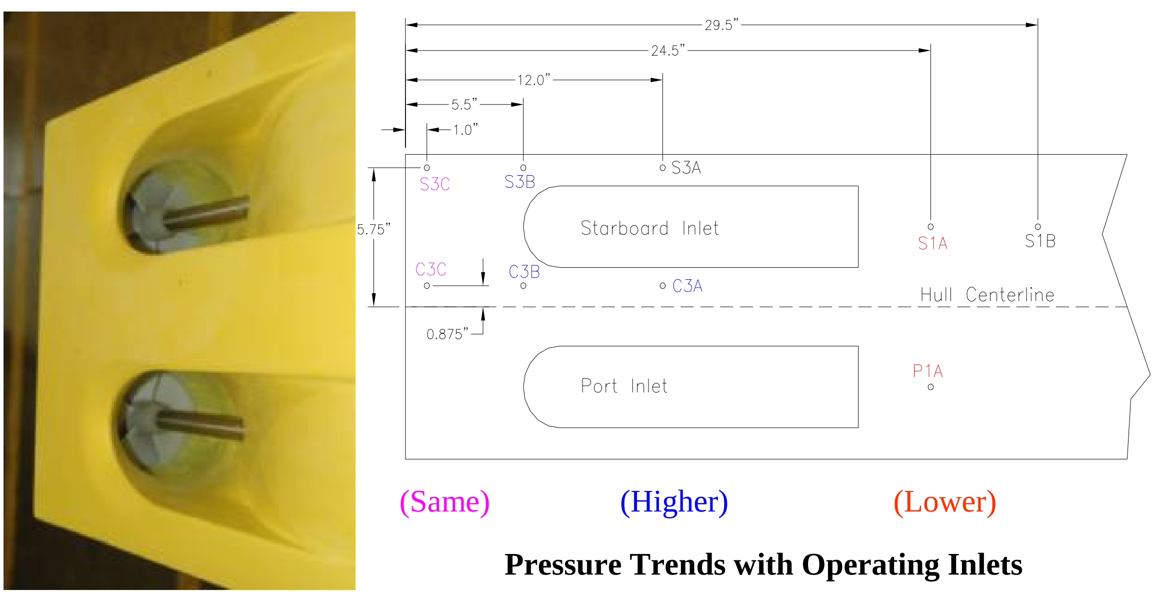

FIGURE 4 – PRESSURE TREND REGION ON THE AFT HULL WITH OPERATING WATERJET INLETS

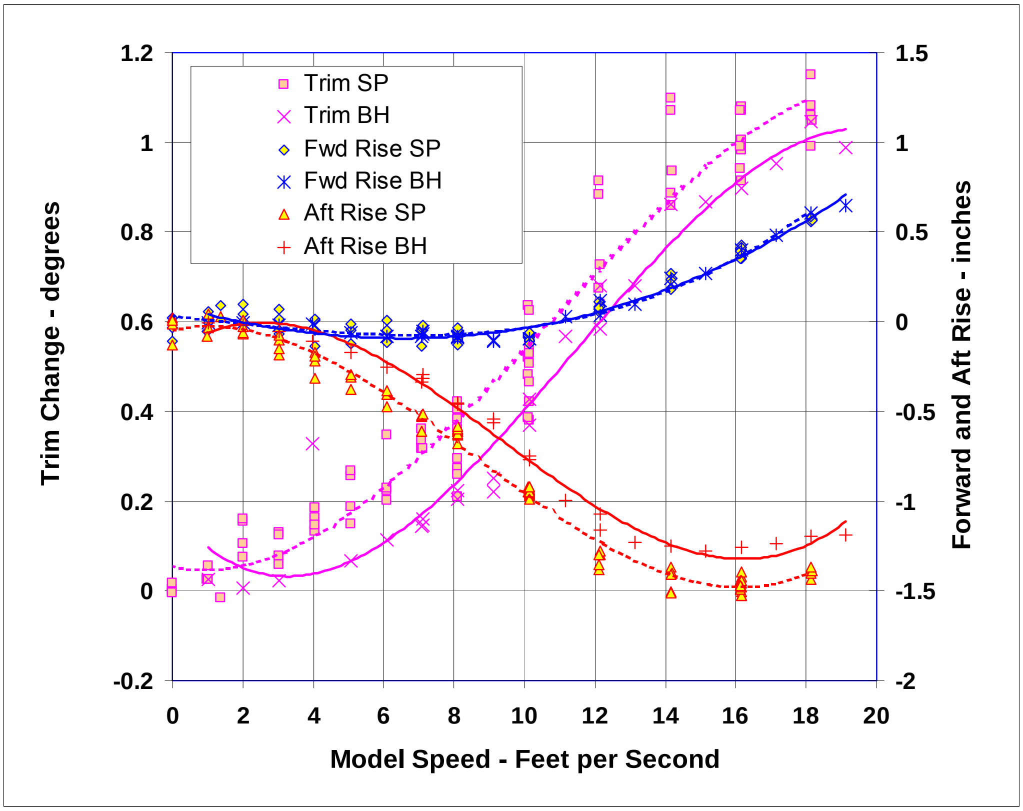

FIGURE 5. COMPARISON OF BARE HULL AND SELF-PROPULSION TRIM AND FORE AND AFT RISE

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Glossary of Acronyms:

CCDoTT - Center for the Commercial Deployment of Transportation Technologies
CFD - Computational Fluid Dynamics
DTMB - David Taylor Model Basin
JVR - Jet Velocity Ratio
NSWCCD - Naval Surface Warfare Center, Carderock Division
SDD - Systems Development Division

Project 05-6: High Speed Trimaran Technology Development and Application for Benchmark Design Validation of Heavy Air Lift Seabasing Ship (HALSS)

Author: Dr. Igor Mizine, Sr. Manager, Special Projects, CSC / Advanced Marine Center; 1201 "M" St., SE, Washington, DC 20003

Abstract: This project examines the feasibility of designing a 35-knot ship capable of delivering early entry of combat units up to 200 miles inland from a floating base 100 miles offshore. This is accomplished by loading, fueling, launching and recovering C-130J aircraft, while carrying enough cargo, troops and fuel to allow the aircraft to move 8,000 tons of troops and materiel to Joint Operating Theater 300 nautical miles away during 10 days of flight operations. The ship can also launch and recover US Army HOVER BARGEs and helicopters, and accomplish a Strategic Mobility and Combat Logistics mission including transport of Marines and their helicopters. The ship is designated HALSS (Heavy Air Lift Seabasing Ship).

The concept design utilizes a trimaran hull about 328 meters (1,075 ft.) long and 55m (180 ft.) wide, augmented by removable sponsons to provide a flight deck about 337m (1,100 ft.) by 83m (274 ft.) wide. The ship provides enough RoRo, container, palletized cargo, fuel and troop accommodations to support 10 days of in-theater flight operations delivering 800 tons per day of troops and materiel from offshore to a point 300 miles away, after a 10,000 nm transit at 35 knots. Flight operations can proceed in weather conditions up to sea state 6. About 200 MW of power is provided by four propellers. Two large slow-speed diesels are directly coupled to the two center hull propellers, and four large medium-speed diesel generators in the center hull power two electric propulsion motors, one in each side hull.

The study includes a general arrangement, machinery arrangement, hull forms development, powering estimates based on CFD calculations and model test results, seakeeping analysis, including motions and sea loads prediction, maneuverability analysis, basic structural design calculations and drawings, weight estimates, and intact and damaged stability analyses, two building strategies suitable for several available shipyards, cost estimates, and recommendations for further design and engineering studies are also provided.

This study also shows that the basic ship design concept can accomplish the combined strategic mobility and seabasing missions of transporting rotary-wing aircraft and combat personnel from CONUS or an advanced base to a Joint Operating Theater at high speed, and then operating as a major Seabase Ship in theater for a sustained time. The cost of the ship is estimated to be between $1.8B and $2.1B assuming the ship is built in a U.S. commercial or dual use shipyard.

Technical Objectives and Approach:

1. Objective: Provide further HST technology development and validation by CFD calculations and model tests in the critical areas of hull form optimization, propulsion and structural design.
    - Various hull forms developed and analyzed. Based on CFD calculations optimized side hulls configuration was verified.

2. Objective: Investigate HST technology transfer to HALSS concept, which was evaluated in the course of the CCDoTT FY04 study. Reduce the technical and developmental risks in these applications by performing vital at this stage of HALSS concept development selected model tests to verify resistance characteristics.
   - MQLT, FLUENT and WASIM calculations were applied for powering and seakeeping predictions. Resistance and flow calculations were verified by comparison with results of model testing.
3. Objective: Complete technical feasibility analysis and risk assessment study to build and operate HALSS. Build strategy analysis and a construction plan.
   - Comprehensive buildability analysis was performed. Concepts of "one and multi unit(s)"were developed. Build plan and organization scheme were developed and reviewed by selected representatives of the shipyards. Cost estimate was prepared.
4. Objective: Develop the HALSS-C130 simulation model to demonstrate the operational scenarios of Trimaran based take-offs and landings. This capability will help verify the operational assumptions used in ship design and airplane modifications and support the refinement of the ship design subject to the C-130 requirements.
   - Operational simulation models of C-130J were developed and demonstrated. Trade-offs of various HALSS parametric features was performed.

Project Summary:

Significant Results:

1. HALSS test results proved the reliability of the HALSS powering requirements and demonstrated good comparison with the CFD resistance prediction.
2. Longitudinal movement of the side hulls to the middle stagger position, which was tested based on theoretical predictions and analysis, proved to be fully validated by the results of model tests. The difference between required effective power for different staggers reached 60%-70%. This result needs further analysis and extensive CFD application, and can potentially lead to appearance of new design concepts exploring this finding.
3. The design approach for the wave-piercing bow bulb, developed for the High Speed Trimarans in the course of the previous CCDoTT projects, proved to be very efficient for the HALSS. In comparison the stem bow (no bulb) the Wave-Piercing Bow Bulb gave about 9% reduction of resistance in all speed range.
4. The SAGA software has been successfully integrated with the DNV WASIM hydrodynamic analysis software to create an effective numerical structural load and hydrodynamic motions analysis tool. The development and integration of the software allows the model and wave loads for a large number of hydrodynamic runs to be reliably set up, and ensures a consistent assessment of vessel responses against a specific set of criteria. The criteria applicable to this vessel's dual roles of transit and naval aircraft operation have been defined and implemented, and an initial assessment of the vessels response to a matrix of sea states, speeds, and headings has been documented.
5. Buildability analysis proved the commercial approach for building and maintenance of the HALSS as one unit for dock, allowing 180 feet breadth, and as "multi-unit and joining afloat" concept at majority of the existing U.S. dual and commercial shipyards.

The organization of commercial building of HALSS is further detailed. Cost estimate based on PERCEPTION ESTI-MATE model is developed.

6. Various naval arch & engineering studies are performed for multi hull and high speed HALSS design concept: maneuverability study, structural design and weight estimate, arrangement designs for general internal spacing and for machinery compartments. These results are unique and can be used as design prototype data base for further studies of similar innovative ships.

Problems:

Flow measurements in NSWCCD for the new type of the HALSS skegs in the center hull were not performed. It did not allow proceeding to center hull propeller design estimate. This testing has been planned for $40k from ONR to be paid directly to NSWCCD. It has to be done in the course of the FY06 project.

Next Steps:

In the next phase of HALSS development it is necessary to concentrate efforts in the following directions:

- Broad parametric evaluation of the HALSS technical requirements in coordination with US Army, USMC and US Navy mission requirements. This parametric research should be based on design modeling of the multihull type of the ships and implementation of the powerful solver allowing performing sufficient number of various calculations of HALSS characteristics as function of technical and mission requirements.
- Continue verification of the HST technologies and tools by performing flow measurements and seakeeping model tests. The results would be important contribution to the Navy's Sealift R&D program and would allow proceeding in the HALSS development study with reliable propulsion design estimates and motion/structural loads characteristics.
- Further refinement of the HALSS technical solutions, including Hull Forms (mostly for optimization of the center hull – skeg interaction); propulsion in the side hulls (mostly for reduction of the side hull propulsor emergences in seas); and selected engineering in the areas of flight deck structural and material designs.

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    - Rick Thorpe, Bob vom Saal, Laurent Deschamps, Dr. Igor Mizine and Michael Starliper. “An Approach to Affordable Shipbuilding.”
    - Poster: "Heavy Air Lift Trimaran."

Glossary of Acronyms:

HST – High Speed Trimaran
HALSS – Heavy Air Lift Seabasing Ship
JHSS – Joint High Speed Sealift

Project 05-8: Development of a Route/Mission Dependent Prediction Program for Rational Structural Dynamic Loads for High Speed Sealift Applications, Phase II-A

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Abstract: Structure designs for conventional hullforms usually rely on past design experience, which today is best represented by Classification Society Rules or U.S. Navy Design Data Sheets. However, past design experience can only apply to ships of similar type, size and speed to those of the past. In the absence of design loads for similar ships, a reliable analytical tool is needed to calculate the dynamic loads for new designs. Alternatively, expensive experimental investigations would be necessary, especially for predicting impact and slamming loads. The key to predicting structural loads is in accurate prediction of the vessel's response to the sea-conditions. Various frequency-domain ship response programs can only handle traditional hullforms, except for a very few, such as SHIPMO, which breaks down at high-speeds. Also, time-domain simulation programs and advanced CFD codes are very expensive and time-consuming to run, and extremely difficult to validate for novel hullforms.

As commercial and military interest in High-Speed Sealift continues to grow, the need for reliable structural design and analysis tools is becoming extremely important. The objective of this research project is to satisfy both the DoD and commercial sector requirements for fast sea transport by developing the ability to accurately predict the structural loads that will be experienced by high-speed ships, and which is suitable for use with all of the candidate high-speed hullforms.

In order to address this critical need, a three-phased integrated methodology to predict the route/mission-dependent rational structural dynamic loads for high-speed multihulls was proposed to CCDoTT back in FY 2001. In response to this, a Phase I effort was funded, under which an overall working model of a frequency-domain ship motion and loads model was developed, incorporating a route-based mission profile module to provide a description of the ships' overall lifetime loads. The results of the Phase I effort were highly commended by CCDoTT, USTRANSCOM and other sponsoring agencies, and were also presented to a wider international audience at the World Maritime Technology Conference in San Francisco, CA in October 2003, with excellent acceptance and support.

The work conducted in Phase II-A is part of the follow-on Phase-II effort of this integrated methodology. The scope of the Phase II effort is to develop a deterministic time-domain motion and loads simulation analytical model which, when integrated with the frequency-domain motions program developed in Phase I, will complete the overall methodology by including the ship slamming and impact loads contributions. In follow-on efforts, a complete rational load prediction and seamless design procedure will be developed for combining (i) still-water loads, (ii) wave-induced loads, and (iii) slamming loads. This integrated methodology will also provide the basis for development of a probabilistic approach for a reliability-based structure design

standard. Under the current Phase II-A efforts, candidate high-speed hullforms were identified along with a determination of their seaway motions for the most probable environmental and operational conditions that could lead to slam events. In addition, slam-induced load estimation algorithms were developed, and a test case was executed to determine the corresponding wave parameters and vessel motion responses in the time domain and to obtain the corresponding slam loads. In Phase II-B (FY06), the slam prediction module will be integrated with the Phase I frequency-domain module to develop the integrated methodology and tool-set, along with some preliminary verification of this integrated prediction model using limited experimental and sea trials data. A more thorough verification and validation against several available sea trials, experimental data and results using Classification Society rules for existing ships are proposed to be performed in Phase III (outyear).

The prospective end users of this unique and timely capability would be multiple, ranging from the U.S. Navy (N42, NAVSEA PMS325, 05D and NSWC-CD), MARAD, MSC, TACOM, USTRANSCOM, Classification Societies, and other commercial marine sectors.

Technical Objective:

The specific objective of this proposed effort was to complete the first part of the second phase of an already completed Phase I program of work, which would create a ship motion and dynamic load calculation program that would be suitable for use by Designers, Classification Societies and the U.S. Navy to predict the structural loads of high-speed ships. The program will be suitable for both advanced monohulls and multihulls such as catamarans and trimarans. The second phase effort, part of which has been conducted here as Phase II-A, will complete the ultimate load model and the rational design methodology developed in Phase I by including the prediction of slamming and impact loads for the practical design of structure for advanced high-speed vessels.

Technical Approach:

The objective of the Phase II effort is to determine the probabilities of slamming and the loads associated with slamming, which can be predicted using a time-domain program that will be developed in the current phase. Under the current effort, Phase II-A, slamming load prediction algorithms were developed, demonstration of the slam prediction methodology was conducted on three different high-speed hullforms, and some limited applications of the slam load estimation were conducted. In the follow-on effort, Phase-II-B, the slam prediction methodology and algorithms developed under the present effort will be coded and integrated with a time-domain simulation program, such as POWERSEA, to develop an integrated tool-set to predict slam loads on high-performance and high-speed multihulls. The overall methodology that is being developed to predict rational structural loads for high-speed vessels is illustrated in Figure 1.

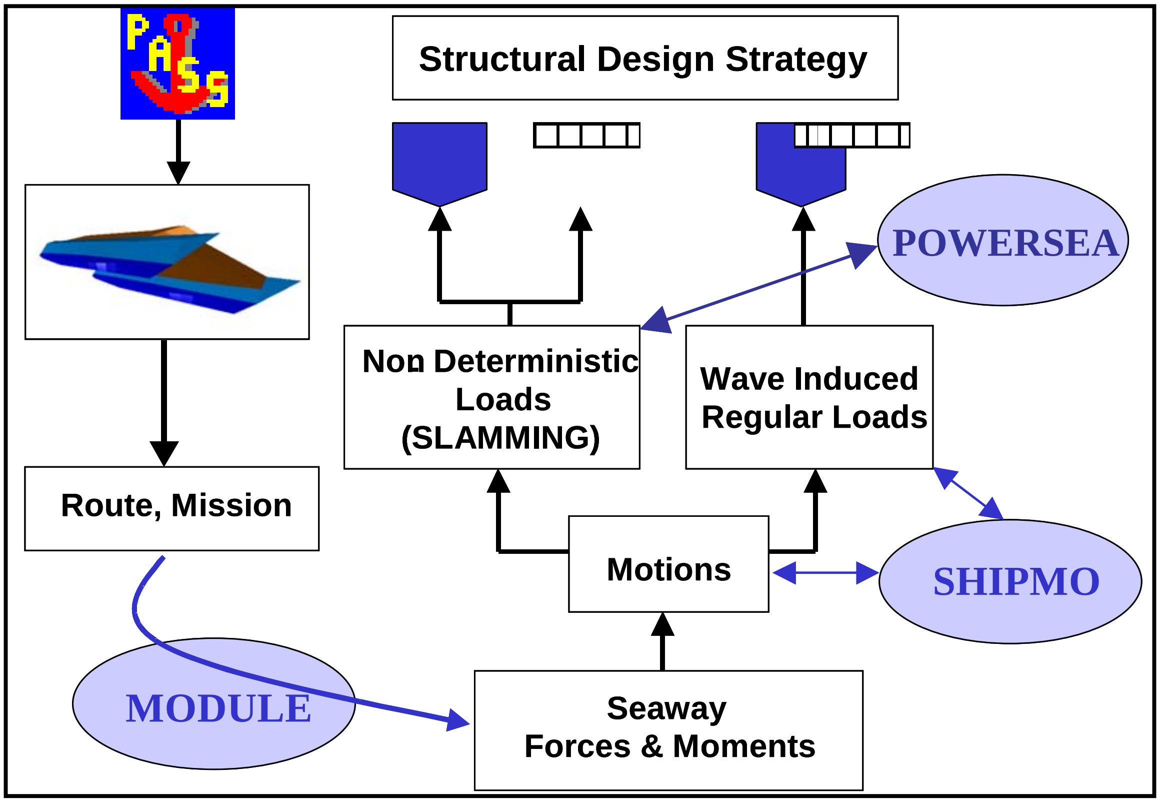

Figure 1 – Rational Structural Loads Prediction Methodology

Project Summary:

Under the present work scope, the following tasks were performed:

- An extensive literature review was conducted on research and development work done in the area of the water entry (impact or slamming) problem for conventional ships and high-speed multihull vessels.
- A rationale was developed to identify the most probable combinations of operational elements, such as speed and payload, and environmental elements, such as heading and sea-states, for the prescribed route/mission that will lead to any considerable impact and slam events based on certain threshold values of slamming parameters.
- Three different high-speed hullforms, representing a wide spectrum of vessel types that are currently in use and are of interest to future commercial and military applications, were identified and modeled. The selected hullforms are shown in Figure 2.

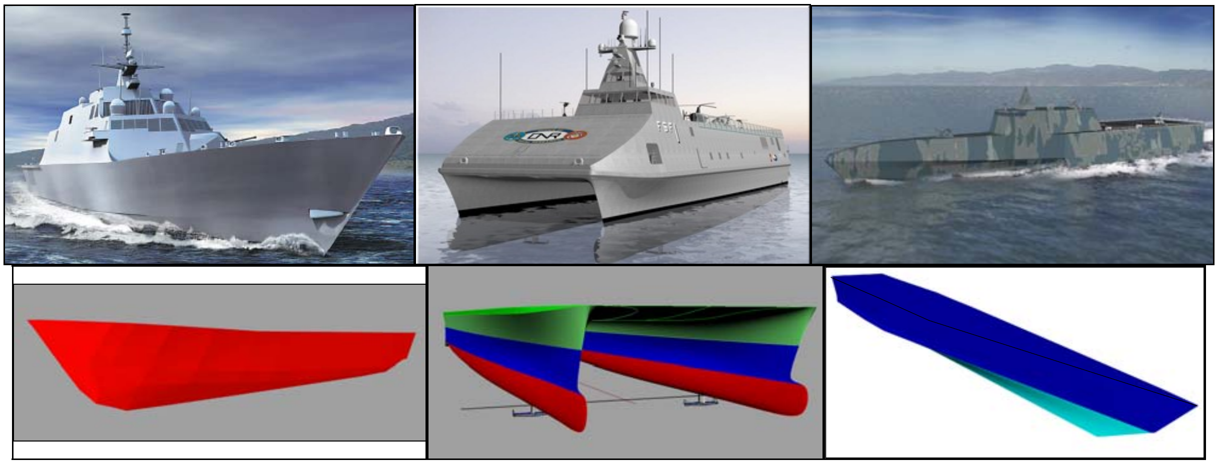

Figure 2 – The Selected Hullforms

- Statistical values of vessel motion responses were obtained using the Phase-I identified frequency-domain program (SHIPMO) for all three hullforms. The motion response statistics were analyzed to determine the probable combinations of environmental and operational (route/mission) elements leading to slamming. The vessel response statistics for one of the hullforms for sea-state 5 are provided in Figure 3.
- Hullform comparisons were conducted for all three selected hullforms with existing and available data of other comparable hullforms; firstly to verify and validate the vessel motion response output from SHIPMO, and secondly to develop preliminary slam occurrence and load estimation algorithms.

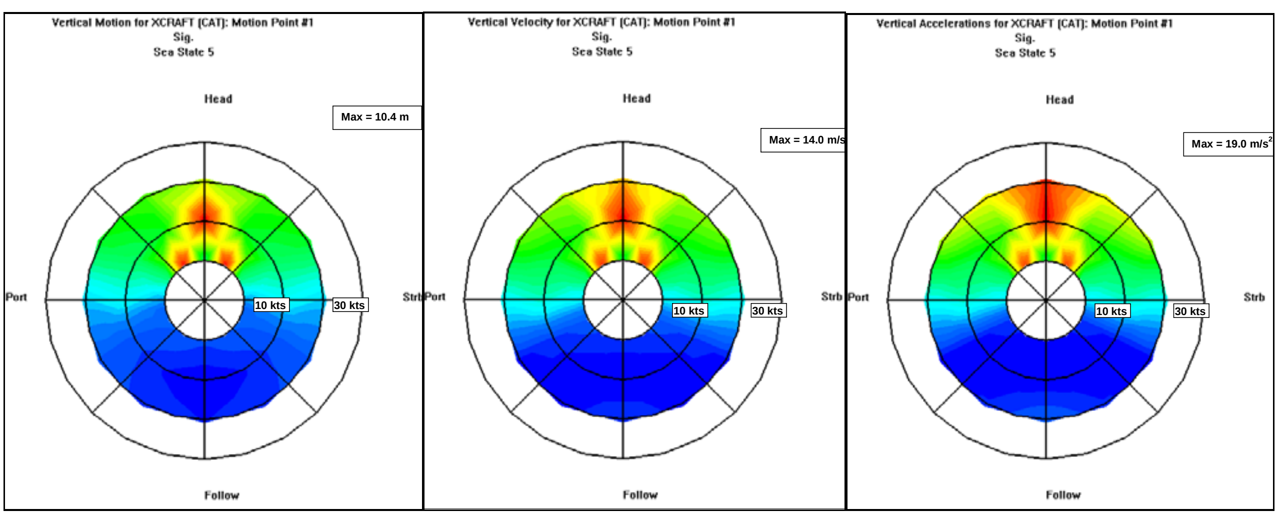

Figure 3 – Vessel Response Statistics for Catamaran

- Based on the literature review, slam load prediction and slam pressure estimation algorithms were developed for high-speed hullforms which could be applied to various vessel types and for varying degrees of route/mission conditions.

- A slam load prediction methodology was developed based on the slam load prediction algorithms and using a strip theory based time-domain simulation program. The time-domain program was simulated for one of the selected hullforms for the route/mission element combinations identified as probable for slam occurrences. The time-domain simulations provided the values of slamming parameters that can be used to calculate the slam loads based on the slam algorithms developed. Figure 4 provides a section of time history showing the vertical velocity and submergence of a location of interest on the bow of one of the selected hullforms.

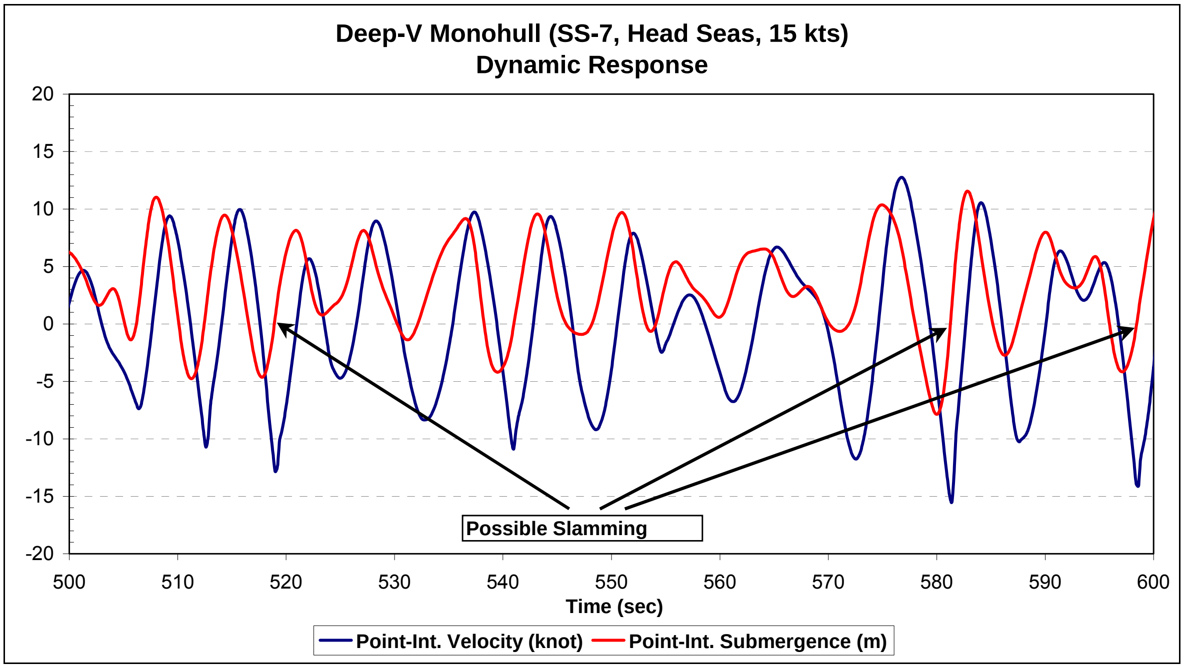

Figure 4 – Time History Excerpt of Vertical Velocity and Hull Submergence

- Methods and processes were identified to extend and apply the slam load prediction methodology developed to other hullforms in the follow-on phase. In addition, other time-domain simulation programs were identified that will be analyzed during the follow-on effort and integrated into the route/mission based dynamic load prediction methodology.
- Ongoing collaborative discussion efforts were performed with both NSWC-CD and ABS to ensure that NSWC-CD can assist with the verification and validation of the final integrated program during the follow-on phase, and that ABS can implement the same into their rule-making process.

Referenced Deliverables:

1. "Final Report: Development of a Route or Mission-Dependent Approach for the Calculation of Rational Structural Dynamic Loads for High-Speed Multihulls", CDIM-SDD Final Report No. 727-1, CCDoTT, CSULB, Long Beach CA. October, 2002.

Significant Results:

Overall, the strip theory frequency-domain model was found to provide an acceptable level of fidelity for the motions data. It was verified that SHIPMO output is equally credible for both high-speed monohulls and multihulls. Hullform comparisons provided confidence in the motions response data and the probable route/mission elements for slam events that could be carried through to the estimation of the slam loads. The shortcoming of the current SHIPMO version of not being able to model trimarans needs to be overcome during the follow-on phase by either utilizing the next version of SHIPMO, currently under development, or employing some other frequency-domain program that can model multihulls, such as SWAN/WASIM, TRIDENT or VERES. However, such programs also have to be evaluated based on their relative ease and strength of applicability, level of validation for various high-speed hullforms and route/mission ranges, and cost-to-benefit ratio of implementing and integrating within the scope and budget of this program of effort. However, even with its current limitations, SHIPMO is still a tool of choice for its ease of use, low computational cost, and its intrinsic capability to model multihulls.

Another conclusion derived from the hullform validation effort was that the interference effects between the hulls for the multihulls has little significance in influencing ship motions and loads in the vertical plane, especially in the high-speed ranges where the wake interferences are minimal to none due to higher speeds of the vessel. Similar conclusions were also drawn during the Phase I study based on the analysis of various catamarans. Based on such conclusions, head and following seas analyses would deem to be adequate for the first order estimation of extreme loads. Therefore, motion response data and the corresponding global and slam loads for trimarans, based on modeling the center hull only, would be acceptable for the purpose of early-stage design. Load estimation algorithms developed from hullform comparisons also corroborate such conclusions. However, for the detail design of the multihull vessels, other headings and slower speeds also need to be analyzed to clearly determine all the governing load cases for which modeling the side hulls become imperative.

The development of a slam prediction methodology and the associated algorithms, and its implementation on a high-speed hullform, clearly demonstrated the viability of the procedure. This provides the basis for extending the procedure to other hullforms and allows the development of an integrated program with an associated time-domain simulation tool.

It was also obvious from discussions and inputs from NSWC-CD and ABS that all branches of the maritime community that deal with high-speed vessels can benefit from the development of a tool-set that can provide early-stage design load estimates for high-speed multihulls which is rationally-based and easy and cost-effective to compute and implement.

Next Steps:

Based on these conclusions, there is serious potential for a very significant contribution to the state-of-the-art in the development of a rational approach to structural design for high-performance vessels. To that effect, presented here is a brief outline of the recommended tasks for the continuation of this effort into the follow-on phase. Highlights of the work to be accomplished in Phase II-B are as follows:

- Conduct time-domain simulations and implement the slam load prediction methodology to the other selected hullforms. Obtain the corresponding slam pressures for the probable combinations of environmental and operational elements (route/mission) leading to slam events.
- Convert the slam pressures to both local and global lifetime maximum loads. Obtain extreme value statistics of both the global loads and local slam loads.
- Integrate the time-domain slamming program into the overall route/mission dependent program developed during the previous phases.
- Develop a rational prediction process to use the calculated load statistics and estimated extreme loads in practical ship structure design.
- Conduct verification and validation, with collaboration from NSWC-CD, for the selected hullforms with the available experimental and sea trial data. Engage ABS in identifying a process to incorporate the rational load prediction method into their rule-making procedure.

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3. "Slam Prediction Algorithm and Simulation Summary Report", CDIM-SDD Report No. 814-3, CCDoTT, CSULB, Long Beach, CA. January 23, 2007.
4. "NSWC-CD and ABS Collaboration Summary Report", CDIM-SDD Report No. 814-4, CCDoTT, CSULB, Long Beach, CA. January 23, 2007.
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Presentations:

- David Lavis and Manish Gupta. “Route / Mission Dependent Prediction Program for Rational Structural Dynamic Loads for High-Speed Multi-Hulls, Phase II-A.” Presentation to Office of Naval Research, Arlington, VA. December 2, 2005.

Glossary of Acronyms:

ABS - American Bureau of Shipping
CCDoTT - Center for the Commercial Deployment of Transportation Technologies
NSWC-CD - Naval Surface Warfare Center, Carderock Division
CDIM-SDD - CDI Marine Systems Development Division

Project 05-9: Summary Review of Alternative Shipboard Powering Systems for Naval and Regulatory Review

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Abstract: The most recent and authoritative prior work published in this area was a multi-year effort managed by then JJMA (now Alion JJMA) that was terminated in 2003. Our review of this report concluded that this effort could not form a reasonable basis for this study for a number of reasons—in particular: (i) the long time frame of reference (20 to 25 years in the future); (ii) the highly immature current state of the technology employed for the reactor system (multiple closed Brayton Cycle, Helium Cooled Gas reactors); (iii) several potentially important issues regarding reactor safety; (iv) unsubstantiated fuel enrichment and corresponding refueling interval; (v) the unrealistic speed and powering required for the ships to maintain the service intended (45 to 50 knots sustained); and (vi) the absence of any tangible basis for a realistic economic evaluation.

Our review of other prior published work on the subject similarly revealed the absence of authoritative cost estimates for the propulsion system concepts employed. In most cases a standard $1,000 per KW was assumed for the total nuclear propulsion system, a figure associated with current 1000 MWe land-based central power plants, and without any informed technical back up to the much smaller and more complex ship propulsion system. Thus, it was necessary that the study team initiate its own conceptual design of a state-of-the-art nuclear propulsion system, and, because of the shortened planning horizon, we based our design on a Pressurized Water Reactor (PWR) system, a technology that has been well proven in 50 years of service in both the central station and marine propulsion applications. Since our team included an experienced nuclear propulsion systems supplier, Rolls-Royce Nuclear (Rolls-Royce) and a highly competent propulsion and power conversion systems supplier, DRS Technologies (DRS) as well as a ship design firm well experienced in conventional and high speed ships (Alion/JJMA), the concept designs developed in this report are believed to be feasible technically and to form the basis for authoritative and realistic cost estimates of the total ship systems considered for a future high speed service as compared with conventionally powered ships in current service.

Recent reports by both the Congressional Research Service and the General Accounting Office have indicated that the U.S. Navy is undergoing a similar comparative analysis of nuclear vs. conventional powering for naval combatant ship applications. In addition to the pure commercial containership design, our study also briefly examined the potential feasibility of using a nuclear plant that is similar to the plant selected for the larger containership for powering a large Roll-On Roll-Off (RoRo) multi cargo ship suitable for high speed logistical supply such as the U.S. Navy's TAK class of vessel. The baseline ship design used in this review is the *USNS Gilliland*, the former *Selandia*, a three-shaft containership converted for TAK mission by Northrop Grumman Newport News in 1993. Although the study concluded that a new design very high speed (~35 knots sustained) Naval Auxiliary appears completely feasible technically, the penalty in cargo carrying capacity is substantial for a vessel of the same proportions as *Gilliland*. Accordingly, a lengthened and reduced power (50%) alternative was examined that resulted in

no payload weight reduction and about a 32 knot speed capability. In the case of the RoRo mission, economics is only one factor in mission capability and the ship's operational profile is very different than a pure commercial vessel engaged in continuous international trade. Although any purely economic comparison with a conventionally powered alternative requires access to information that is not available in the public domain, it would seem that the high to very high speed and fuel independency of either of the Naval Auxiliary variants studied for the nuclear logistical supply and re-supply mission could be a valuable asset under many operational scenarios involving a "long reach" engagement typical of the Pacific or Indian Oceans.

The study does not provide any economic evaluation of the LMSR type Auxiliary vessel but construction cost estimates of $375 Million for the basic ship + $620 Million for the nuclear propulsion system (the fuel core approximates the life of the LMSR type Auxiliary ship) for a total of $995 Million were developed.

Technical Objective:

The primary objective of this report is to evaluate the technical and economic feasibility of high speed, "alternatively fueled and powered" commercial shipping in long distance express container service. In this case the alternative selected for comparison with a conventional fueled vessel is a large ship powered by a state-of-the-art nuclear reactor and propulsion system. In addition to the experienced nuclear ship design technical team referenced above, our study team also included individuals highly experienced in commercial and naval ship operations and support. This team was expressly selected to provide sufficient credibility in supporting the technical and economic assumptions and results achieved.

Technical Approach:

In order to achieve this objective, the team reviewed prior work sponsored by CCDoTT as well as other subsequent reviews and reports as cited in earlier deliverables under this contract. After this review, the team prepared concept designs of two reference nuclear powered ship applications along with rough order of magnitude cost estimates for mature services that realistically could be considered for application within the next 10 to 15 years.

Project Summary:

The technical results of the study indicate that both high-speed nuclear powered ship alternatives are technically feasible and should perform creditably and safely in their respective services. Although the particular vessels selected as references for the concept studies were initially found to be limited in realizing the full advantages of the high powered nuclear propulsion and power system developed by Rolls-Royce Nuclear and DRS Technologies for this study, subsequent design analysis performed in the course of our study has concluded that the basic performance objectives as cited in Table 1 are entirely achievable in both applications particularly when subjected to complete new ship designs capable of accommodating the high power characteristics required.

TABLE 1- LISTING OF MAJOR STUDY ASSUMPTIONS/ATTRIBUTES, OBJECTIVES & RESULTS

	Major Study Assumptions Applied	Principal Study Technical & Performance Objectives	Principal Study Results
1	Large Ship Types	Ship A 8,000 TEU Containership Ship B RO/RO similar to USNS TAKR Applications	Ship A 9,200 TEU Containership Ship B RO/RO similar to USNS TAKR Applications
2	High Ship Transit Speed	A Greater Than 33 knots Sustained B Greater Than 35 knots Sustained	A 34+ knots Sustained B 32 to 35 knots Sustained (*)
3	Proven Reactor Type	Single Very High Powered & Large Pressurized Water (PWR) Both Ships A & B	Ship A - Large Very High PWR Ship B - Similar Design PWR @ 100% & 50% Power of Ship A
4	Commercial Service	Trans-Pacific Express Service Ship A Only	Trans-Pacific Express Service Ship A Only
5	Nuclear Safety Criteria	Similar to Land-Based Commercial Applications & NS Savannah; NRC Reviewed & Intl. Certified	Similar to Land-Based Commercial Applications & NS Savannah; NRC Reviewed & Intl. Certified
6	Auxiliary/ Emergency Powering	Significant Back-Up Power For “Take-Home” & As Necessary, Port Entry	Significant Back-Up For “Take-Home” & As Necessary, Port Entry
7	Ports & Cargo Handling Ship (A) Only	Two Port Service; State of The Art Port Handling For Rapid Turn-Around (~100 Hrs/RT)	Two Port Service; State of The Art Port Handling For Rapid Turn-Around (~100 Hrs/RT)
8	Nuclear Vessel Support	“Dual Use” Approach	“Dual Use” Approach
9	Refueling Interval	Ship A ≥5 Years Ship B > 10 Years	Ship A ~5 Years Ship B >10 / >20 Years*
10	Economic Evaluation Basis	3rd Thru 10th Of a Kind	3rd Thru 10th Of a Kind
11	Shaft Horsepower	Ship A 200,000+ Ship B 200,000+	Ship A 273,000 on 3 shafts Ship B 100,000 on 2 shafts

(*) Higher values depending on new ship and plant design and specific service requirements

Such a positive result has not been obtained in the economic analysis. Nuclear fuel costs have almost tripled in the past two years due to a marked change in the supply/demand balance of the global nuclear energy market. “Basic nuclear fuel costs” involve the mining and beneficiation of raw Uranium into a finished state and form ready for core fabrication and, thus, include combined costs associated with the mining of raw uranium, U_3O_8 (“yellowcake”), its conversion to Uranium Hexafluoride (UF_6), the enrichment of this intermediate product to the level specified by either gaseous diffusion or centrifuge processes, and finally its reconversion to the final product of enriched UO_2 ready for core fabrication. This increase has been particularly dramatic in the past year and has reduced nuclear’s advantage over conventional fossil fuels in basic energy costs significantly from what appeared evident as recently as a year ago. The results indicate – at *present* marine fuel prices - the fuel savings associated with proven and available nuclear technology cannot underwrite the added capital and other running costs to compete with conventional diesel ships at this time. However, impose a requirement, such as, requiring all vessels to burn low-sulphur fuels and the economic results are very different. The nuclear ship would be economically superior. Moreover, our study assumes that within five years time there will be a requirement imposed on all vessels burning high-sulphur residual fuels to burn higher grade low-sulphur Marine Diesel Oil (MDO) when approaching the west coast of the United States and other coastlines elsewhere in the world, the cost of which on average is approximately twice as expensive as residual fuels. Under this scenario, assuming the ship spends 30% of its fuel budget on MDO, the breakeven point for the nuclear-fueled vessels is approximately $89 per barrel of oil.

The dominant factor in the comparative fiscal equation will continue to be fuel costs – both nuclear and conventional fuel. We have used the numbers as they exist today, but recognize that during the past several years and especially during the past year both fuel types have experienced significant trends and spikes. These conditions deserve further discussion.

In regard to the Containership application the study uses numerous assumptions for both the nuclear-fueled ship and its diesel counterpart that the study compares against, too many to list in this abstract. However, the major capital assumptions are:

> 9,400 TEU (25 knot) Diesel Fueled Vessel Construction Cost = $150 Million.
>
> 9,200 TEU* (34+ knot) Nuclear Vessel = $722 Million + Initial Fueling of $113 Million for a total of $835 Million.

*Note- 200 TEU's of containers are removed to provide more side impact protection for the nuclear containment vessel.

Thus, the decision to "go nuclear" in the case of the commercial containership is almost entirely dependent on expectations of marine fuel costs over the foreseeable future. It is true that oil prices have moderated somewhat since they peaked at about $80 a barrel a few months ago, but the question remains, for how long? $90 a barrel is not far from the last peak, and the additional critical issue (to commercial shipping interests) of currently imposed and pending marine emissions restrictions remains.

Although future oil prices are a paramount issue in the case of the commercial containership, the authors do not believe that such is necessarily the case with the Naval Auxiliary application that has been described in this study. A "commercial type" very high speed nuclear ship based on a new ship design similar to our Ship B Naval Auxiliary would seem to represent a reasonable candidate for the "MPF-F Seabasing" program of the Department of Defense (DoD) and Navy and, at the same time, would serve as an excellent prototype for a subsequent commercial containership application, should oil prices continue to rise above the thresholds described in this study. Should that eventuality come about, embarkation on a jointly merged program by Government and Industry will serve the national interest in both dimensions, provided that the program specifics follow the "Shippingport Paradigm" and "NDF" suggestions that we present in the Report.

<u>Next Steps:</u>

Where to go next has been discussed with CCDoTT, but many of the factors and assumptions discussed in the study still warrant further review. They are:

1. Review and update American Bureau of Shipping (ABS) and potentially other classification society rules. Initial discussions with ABS indicate that this will require funding.

2. Conduct further discussions with major insurance carriers and pools regarding insurance costs, liability and umbrella provisions.
3. Hold discussions with U.S. and U.K. Naval personnel to assess interest and viability of the Naval variant.
4. Meet with labor unions to discuss work rules and safety
5. Meet with port authorities to discuss safety and turnaround times.
6. Meet with various maritime companies to assess their interests in large fast containerships for long distance express-type service.

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Project 05-10: Feasibility Assessment of Short Sea Shipping to Service the Pacific Coast

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Abstract: The study of short sea shipping service on the Pacific Coast addresses the business combination of port, sea and inland transport and supporting infrastructure for both domestic modal substitution and for feeder service connections in international shipping networks.

With a positive finding from the initial economic and business case assessment of short sea shipping performed in FY04, continuing work involved development of detailed ship planning and design, port development plan, and service plan for specific applications in the marketplace, and. Our view is that the commercial viability must come first, and that the effort be focused on the timely implementation of the service.

Potential end-users of a proven viable short sea service include mid-size and smaller trucking companies, national domestic transportation providers such as BNSF and Union Pacific; international transportation providers such as Maersk and NYK; shippers such as General Electric, J. C. Penney, and Best Buy; financial investors such as Lehman Brothers and Goldman Sachs; military users such as the US Navy and US Transportation Command. Westar Transport, part of the study team, is a potential end user of the proposed system.

Manalytics International was the prime contractor and project manager for the study, with Westar Transport as subcontractor with support from CDI Marine Systems, NASSCO, Tedesco Consulting and Scully Capital, participated as direct sub-contractors to Westar Transport.

Technical Objectives:

The objective of the study was to demonstrate the preliminary market, economic, and technical feasibility of a commercial short sea service on the Pacific Coast that handles domestic and international (feeder) freight moving between major transportation hubs and population centers. The effort also addressed the potential emissions of Short Sea Shipping compared to traditional trucking and the military applications of short sea service and vessels including their scope for contributing to military deployment requirements.

Technical Approach:

The overall approach was to apply commercial market requirements to determine the feasibility of short sea service along the Pacific Coast. Commercial requirements include costs and service standards (transit time, frequency, on-time reliability, etc.) that are competitive with today's modes (road and rail). Commercial requirements were determined through surveys of shippers and service providers. Market sizing was derived from assessment of current cargo flows and creation of a diversion model to quantify the cargo available to short-sea service. Vessel requirements were derived on the basis of assessments of port constraints and required vessel speed based on simulation modeling of a door to door model, and an assessment of the resulting ship design trade space using a ship design synthesis model. Economic analysis of SSS compared to traditional trucking in three routes, Northern California to Southern California, Northern California to the Pacific Northwest, and Southern California to the Pacific Northwest was performed to determine the economic feasibility of SSS on the West Coast. Finally, an estimate of SSS emissions was developed and compared to traditional trucking in these three routes using two different propulsion plants and grades of fuel.

Project Summary:

The Cargo Flows and Trade Lane Analysis identified 5,663 truck and rail county traffic lanes, grouped according to a very broad definition of the potential market for west coast short sea service: 107 Business Economic Areas (BEAs)[1] that had at least minimal potential to be suitable for cargo diversion into the coastwise service. Northbound and southbound Pacific Coast shipments in general, with sufficient length of haul or origin/destination pairs that do not fall within a single port area were generally identified as being eligible. Truck cargo was analyzed at the county level in the US. All counties within the states of California, Oregon and Washington were included, and the truck traffic data provided was split into three types, common carrier truckload and less-than-truckload (LTL), and private truckload. US rail cargo, both intermodal and carload[2], was analyzed at the BEA level. This is the most detailed level that can be provided without special permission from the Surface Transportation Board. Each origin / destination pair included traffic mode (truck or rail), length of haul, and commodity type.

The Cargo Diversion Shipper Survey results are based on a relatively small sample and should be viewed as preliminary, subject to analysis in subsequent subtasks of this project, which may include additional survey research with shippers, consignees and transportation companies. In addition, because these results are based on a test of a new transportation concept, where the respondents have no direct experience, respondents' estimates of the likelihood of use, and extent of use if receptive, are likely to be biased downward. To summarize, the principal quantitative results of the survey were:

- About 43 percent of the respondents indicated that they would consider using coastal shipping service as an alternative to their current modes of transportation for North-South shipments along the West Coast.

- Statistical analysis suggests that respondents' (1) average length of haul for eligible shipments, and (2) the percentage of their eligible freight that moves via rail both positively affect the likelihood that they would consider the coastal shipping alternative.

- The main reason for lack of interest in the coastal shipping service was skepticism about the service's ability to provide adequate transit time and reliability, particularly for those respondents with shipments involving a high degree of circuitry (if they were to utilize a short sea shipping service) or perishability.

[1] There are 172 defined Business Economic Areas in the US, see Appendix A for a definitional map
[2] Carload refers to all other types of rail cars other than trailers or containers moving by intermodal car

TABLE 1: 2004 ESTIMATED "FILTERED" TRUCKLOAD (000'S) FLOWS BY ORIGIN/DESTINATION

	Origin BEA								
Destination BEA	Los Angeles, CA	San Francisco, CA	San Diego, CA	Seattle, WA	Sacramento, CA	Portland, OR	Richland, WA	Other	Total
Boise, City, ID	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Eugene, OR	35.5	9.1	2.0	203.5	4.3	61.5	1.5	1.1	318.5
Fresno, CA	0.0	0.0	12.6	25.2	0.0	19.4	93.9	18.4	169.6
Los Angeles, CA	146.5	**7,160.0**	1,382.9	444.6	1,355.8	416.6	110.8	439.5	11,456.7
Pendleton, OR	89.5	1.8	0.2	0.0	0.5	0.0	0.0	0.5	92.4
Portland, OR	102.4	143.3	8.3	396.8	23.2	0.0	0.0	136.7	810.7
Redding, CA	218.2	0.0	21.7	40.1	0.0	3.6	0.0	0.0	283.6
Reno, NV	17.5	0.0	6.9	0.4	0.0	0.6	0.0	0.0	25.5
Richland, WA	17.6	17.7	0.6	0.0	2.6	0.0	0.0	6.8	45.3
Sacramento, CA	1,327.9	0.0	142.7	29.6	0.0	25.4	17.8	17.5	1,560.8
San Diego, CA	1,020.8	734.6	0.0	29.6	126.2	26.4	4.5	46.4	1,988.6
San Francisco, CA	**7,218.4**	0.0	799.1	240.3	0.0	132.2	266.1	109.9	8,765.9
Seattle, WA	238.8	97.9	10.3	252.0	27.7	233.0	0.0	96.1	955.7
Spokane, WA	33.5	9.8	0.7	0.0	2.7	0.0	0.0	2.5	49.2
Grand Total	10,467.5	8,174.3	2,388.1	1,662.3	1,542.8	918.7	494.5	875.3	26,523.5

Source: Global Insight, Reebie Transearch Database, 2004, Manalytics International

- Among those respondents that did express an interest in coastal shipping service, statistical analysis indicates that (1) the total transit time relative to truck service and (2) the all-in price relative to truck service both had significant negative effects on percentage diversion to coastal shipping from current transport modes. The estimated impact of the reliability of coastal shipping service relative to truck was not significant. Furthermore, these statistical results suggest implicit tradeoffs made by shippers between the transit time and price of coastal shipping service.

- The majority, 57 percent, of those shippers that is receptive to coastal shipping service requires at least twice-weekly service, and 32 percent require at least daily service. There is moderate seasonality of demand—relatively heavy in the Summer and Fall, and relatively light in Winter.

The Cargo Diversion Model was developed based on a survey of transportation professionals describe above. In this deliverable, shippers are substituted by county pairs, based on the likelihood that aggregate cargo flows between counties behave similarly to how individual shippers move cargo between these origin and destination points. The model presents a two step process:

- Step One estimates, based on the survey results, the probability that shippers would consider taking advantage of a short sea service; the probability is based on the distance that cargo travels, and the percent of the total traffic that moves by rail between each origin/destination pair.
- Step Two calculates the percentage of cargo diverted given a range of choices on relative price and relative door-to-door transit time.

Relative price represents the all-in[3] price of coastal shipping relative to the all-in price that shippers pay for their current mode of transportation, and is calculated as short sea price divided by current price paid. Relative transit time is the ratio of estimated all-in short sea transit time divided by transit time by truck.

Steps 1 and 2 are combined to calculate tons per year diverted to short sea shipping on a county pair basis:

(Probability of considering short sea shipping * the percentage of cargo diverted * county pair tons per year) = estimated annual tons diverted to short sea shipping service

This calculation was generated for each of the 5,663 county pairs in the dataset.

Another dimension used to estimate diversion tons is ship speed. Adjusting the speed of the ship changes relative transit time values for each county pair; this, in turn, causes a new diversion probability to be estimated for every combination of relative price and relative transit time.

Several different price-transit scenarios were examined to generate potential volumes that would likely portray real-market environments, either currently or in the future. The following

[3] All-in charges are the total costs associated with moving freight from the shipper's door to the receiver's door. Intermodal rail all-in charges would include the railroad freight charges, the dray charges to the railroad terminal at origin, in addition to the dray from the destination terminal to the receiver's door, and any other charges resulting from the intermodal move, such as fuel surcharges. All-in truck charges would include door-to-door dray charges, fuel surcharges and any charge associated the movement of freight from point A to point B by truck. Similarly, short sea charges would include ocean freight charges, plus drayage to and from origin and destination terminals, fuel surcharges and any charges associated with the movement of goods from the shipper's door to the receiver's door via a coastal service. It is important to note that comparing all-in charges across different modes of transportation enables an accurate analysis of competing transportation modal expenditures.

describes the price and transit time scenarios that were utilized to assess the potential divertible truckload volumes.

- Relative price was assigned four different values: 0.9, 0.8, 0.7 and 0.6, representing 10 percent through 40 percent discounts from truck transportation.

- Relative transit time is a continuous variable, uniquely calculated for each of the 5,663 county pairs. Each county was assigned a dray distance to a potential short sea shipping port and there were three different vessel speeds utilized: 24, 27, and 32 knots. For each county pair, relative transit time was calculated as:
    - Transit time by short sea shipping ÷ transit time by truck

- It should be noted that these estimates are, in some cases, based on parameters outside the boundaries of the choices that survey respondents were given. For example, respondents were not presented with choices that involved relative transit times of 1.20. In these cases, estimates were based on an extrapolation of the relative price/ relative transit time relationships. This leads to additional uncertainty in the estimated diversions.

- Finally, although a reliability variable was also included in the survey, results for this were not statistically significant, and reliability, therefore, was not used in the diversion estimates.

Table 2 provides some idea of critical mass and feasible deployments. For example, with a 27 knot average vessel speed and a relative price of 0.7 (30 percent discount for short sea shipping service), the estimated annual diversion in the southbound Seattle to Los Angeles lane is 56,438 truckloads per year. Further, assuming 260 sailings per year, this amounts to 229 truckloads per sailing, southbound. By contrast, in the northbound Los Angeles to Seattle lane there are an estimated 30,313 truckloads per year, or 117 truckloads per sailing, northbound. This amounts to a southbound / northbound ratio, or imbalance, of about 1.96 to 1. However, imbalances could be mitigated via differential pricing for cargo moving in the northbound and southbound directions.

In addition, if the assumption of non-stop service were relaxed, the northbound might be further enhanced by making a northbound vessel call at a San Francisco area port. In this case, at a 30 percent discount, there would be up to 75 truckloads per sailing from Los Angeles to San Francisco plus some small amount, not shown in the table, in the San Francisco to Seattle lane. Of course, if a stop occurred at the San Francisco area port, then the northbound relative transit times would deteriorate somewhat and less tonnage (truckloads) would be divertible in the Los Angeles to Seattle lane.

As noted earlier, these calculations are based on approximately daily, port-to-port service. Changes in this frequency assumption in either direction would have significant impact on relative transit times and divertible tonnage. As noted previously, these diversion predictions reflect the results of the cargo diversion shipper survey that is likely to be biased downward. Nevertheless, these results provide quantitative parameters that can be used in developing preliminary lower-bound estimates.

Four notional point designs for large commercial roll-on/roll off vessels with speed capabilities covering the speed range of interest (24 to 32 knots) given potential port locations, and 24, 48, and 72 hour service goals for Northern California to Southern California, Northern California to the Pacific Northwest, and Southern California to the Pacific Northwest respectively were developed using CDI Marine's design synthesis models. These point designs are summarized in Table 3, and served as input to vessel construction cost estimates, as well as operating and support cost estimates.

TABLE 2: TOTAL TRUCKLOADS DIVERTED BY TOP TEN BEA PAIR, BY VESSEL SPEED AND RELATIVE PRICE (2004 TRUCKLOADS IN 000'S)

Business Economic Area (BEA) Information					Estimated Truckloads Diverted to Short Sea Shipping (in 000's)											
					Vessel Speed = 24 Knots				Vessel Speed = 27 Knots				Vessel Speed = 32 Knots			
					Relative Price				Relative Price				Relative Price			
Rank	Origin BEA	Destination BEA	Avg. Length of Haul	2004 Truck-loads (000's)	0.9 (10% discount)	0.8 (20% discount)	0.7 (30% discount)	0.6 (40% discount)	0.9 (10% discount)	0.8 (20% discount)	0.7 (30% discount)	0.6 (40% discount)	0.9 (10% discount)	0.8 (20% discount)	0.7 (30% discount)	0.6 (40% discount)
1	Seattle	Los Angeles	1,150	490.8	17.6	28.8	42.0	58.1	30.8	42.5	56.4	73.5	50.3	62.9	77.9	96.2
2	Portland	Los Angeles	958	453.6	12.5	19.6	27.9	39.2	20.5	27.9	37.6	50.0	32.6	41.6	52.6	66.0
3	Los Angeles	Seattle	1,156	281.4	8.7	14.9	22.3	31.3	16.0	22.6	30.3	39.8	26.9	33.9	42.3	52.5
4	Los Angeles	San Francisco	395	7,324.4	3.0	8.3	14.9	23.3	6.8	12.5	19.6	28.3	12.4	18.6	26.1	35.2
5	San Francisco	Los Angeles	393	7,449.8	2.6	6.8	11.9	18.2	5.6	10.0	15.3	21.8	9.9	14.6	20.1	26.9
6	Seattle	San Francisco	482	769.6	0.5	4.1	9.3	15.5	3.6	8.1	13.4	19.9	9.0	13.8	19.4	26.2
7	San Diego	San Francisco	486	755.8	0.6	4.1	8.9	14.8	3.6	7.8	12.8	18.9	8.7	13.1	18.4	24.8
8	San Francisco	San Diego	816	293.4	0.4	0.9	4.7	10.3	1.1	4.4	9.3	15.2	6.4	10.8	15.9	22.3
9	Richland	Los Angeles	1,094	122.4	1.0	3.4	6.3	9.7	3.7	6.2	9.2	12.9	7.6	10.4	13.6	17.5
10	Los Angeles	Portland	963	103.5	2.6	4.1	5.9	8.3	4.3	5.9	7.9	10.7	6.9	8.8	11.3	14.3
	Subtotal Top Ten			**18,044.8**	**49.5**	**94.9**	**153.9**	**228.7**	**96.0**	**147.9**	**211.9**	**291.0**	**170.6**	**228.3**	**297.4**	**381.9**
	Remaining BEA pairs			9,199.4	9.2	26.5	54.1	96.1	24.6	48.4	82.8	133.6	55.8	87.9	132.6	189.7
	Total			**27,244.1**	**58.7**	**121.4**	**208.1**	**324.8**	**120.6**	**196.4**	**294.8**	**424.6**	**226.3**	**316.2**	**430.1**	**571.6**

Source: Manalytics International "Diversion Model"

TABLE 3: CHARACTERISTICS OF FOUR NOTIONAL SOLUTIONS

		Baseline w/ Gas Turbine	Baseline MAX	SUPER MAX	SL-7 VARIANT Deep Hull
LOA	FT	832.5	837.7	959.6	980.1
BOA	FT	118	118	118.1	105.5
LBP	FT	794.4	794.4	904.4	900
BWL	FT	118	118	118.1	105.5
DRAFT	FT	19.84	23.66	26.7	23.41
DEPTH	FT	81.4	93.7	102.7	79.91
DISP F.L.	L.T.	31140	37020	47845	33722
DSGN SPD	KTS	24	27	27	32
POWER, Installed	SHP	69954	119829	121536	117768
L/B		6.732	6.732	7.66	8.531
CP		0.691	0.671	0.66	0.577
PAYLOAD	L.T.	10397	12707	16588	12054
	TRAILERS	450	550	718	500 to 600
HULL DECKS		5	6	7	5

Potential port locations for Northern and Southern California, as well as the Pacific Northwest, were explored to determine constraints that these locations might place on the vessel design, or the service timeline. In addition to surveying potential terminal locations, and assessing their associated impacts on vessel requirements and required speed, a discrete event simulation was developed to explore infrastructure requirements. This simulation model included activities from the time a vessel was ready to unload, to the time that all loads had been delivered to receivers, all loads had been loaded onto the vessel for the return trip, and all loads that would be staged for the next vessel were staged. Speed ranges required for each of the three primary routes considered are: 27 to 35 knots for Northern to Southern California; 24 to 27 knots for Northern California to the Pacific Northwest; 20 to 22 knots for Southern California to the Pacific Northwest. Tables 4 and 5 provide a comparison of estimated SSS costs, door to door, to prevailing truck rates in the three primary markets considered assuming a minimum of two 700 trailer capacity vessel sailings per day from each terminal. These tables provide low and high estimates associated with lower and higher required vessel speeds, and also a lower[4] and higher[5] per-load terminal cost estimate. In addition, results are provided with and without the Harbor Maintenance Tax (HMT) applied. In the Northern California to Southern California route, SSS costs compared to prevailing truck rates range from 70% to 100% depending on the assumed scenario (with or without the Harbor Maintenance Tax, with our without favorable negotiated terminal costs, and with a 27 knot cruising speed or 32 knot cruising speed). In the Northern California to Pacific Northwest route, SSS costs range from 67% to 95% of prevailing truck rates depending on the scenario. In the Southern California to Pacific Northwest route, SSS costs range from 36% to 47% of the prevailing truck rates.

[4] Estimated revenue to the port for leasing comparable acreage based on interview of Port of Long Beach by Westar Transport
[5] Four Corridor Case Studies of Short Sea Shipping Services; Global Insight; August 15, 2006

TABLE 4: TOTAL SSS COSTS PER LOAD

	Baseline Vessel Costs			Higher Vessel Costs		
	NC - SC	NC - PNW	SC - PNW	NC - SC	NC - PNW	SC - PNW
Vessel:	$236	$780	$487	$297	$1,068	$546
Trailers:	$21	$26	$31	$21	$26	$31
Yard Tractors:	$21	$21	$21	$21	$21	$21
Truck Drayage:	$270	$270	$270	$270	$270	$270
Terminals:	$28	$28	$28	$28	$28	$28
TOTAL/LOAD:	$576	$1,124	$836	$636	$1,412	$895
W/ HMT:	$651	$1,199	$911	$711	$1,487	$970
Northbound Truck Rate:	$945	$2,375	$3,265	$945	$2,375	$3,265
Southbound Truck Rate:	$693	$963	$1,325	$693	$963	$1,325
Notional Average Truck Rate:	$819	$1,669	$2,295	$819	$1,669	$2,295
SSS/Trucking:	70%	67%	36%	78%	85%	39%
SSS/Trucking with HMT:	79%	72%	40%	87%	89%	42%

TABLE 5: TOTAL SSS COSTS PER LOAD, $120/LOAD TERMINAL COSTS

	Baseline Vessel Costs			Higher Vessel Costs		
	NC - SC	NC - PNW	SC - PNW	NC - SC	NC - PNW	SC - PNW
Vessel:	$236	$780	$487	$297	$1,068	$546
Trailers:	$21	$26	$31	$21	$26	$31
Yard Tractors:	$21	$21	$21	$21	$21	$21
Truck Drayage:	$270	$270	$270	$270	$270	$270
Terminals:	$134	$134	$134	$134	$134	$134
TOTAL/LOAD:	$682	$1,230	$943	$742	$1,519	$1,002
W/ HMT:	$757	$1,305	$1,018	$817	$1,594	$1,077
Northbound Truck Rate:	$945	$2,375	$3,265	$945	$2,375	$3,265
Southbound Truck Rate:	$693	$963	$1,325	$693	$963	$1,325
Notional Average Truck Rate:	$819	$1,669	$2,295	$819	$1,669	$2,295
SSS/Trucking:	83%	74%	41%	91%	91%	44%
SSS/Trucking with HMT:	92%	78%	44%	100%	95%	47%

Next Steps:

In looking forward at where to focus the most attention to both improve the accuracy of the estimates as well as to further reduce costs, it is useful to understand the contribution of each cost sector to the total costs per load on a percentage basis. Figures 1, 2 and 3 illustrate the percentage breakdown of cost per trailer by cost category for each route. Figures 4, 5, and 6 provide a similar breakdown for the vessel costs. In each route, the fuel costs predominate, followed by amortized vessel constructions costs. Some key variables that should be the focus of future efforts include:

- Fuel consumption is the primary factor in costs per load for the SSS operation. Therefore, special attention should be paid to fuel consumption during subsequent work. This should include trade studies of alternative hullforms, as well as power and propulsion.

- Vessel construction costs are the 2nd largest vessel cost contributor next to fuel. Subsequent efforts should engage shipbuilder participation to develop highly producible designs at the least cost possible. The impact of longer production runs on the average cost per vessel should be further explored.

- Truck drayage costs are a significant portion of the total costs per load, equal to vessel costs (including construction and fuel) in the case of the shorter Northern to Southern California route, and second to vessel costs for the longer routes. Truck drayage costs are therefore an area worthy of additional special attention as business models are developed.

- Detailed discussions with port authorities and terminal operators are needed to develop an accurate estimate of terminal costs, which at the time of this writing appeared to be highly variable. If priced as a per-load rate based on a percentage of prevailing container lift-on/lift-off rates it is anticipated that terminal costs will be highly inflated compared to current revenues based on the utilization anticipated from SSS operations. A more favorable rate, negotiated on the basis of replicating current revenue should be pursued.

- Simulation of shipboard trailer maneuvering for specific designs and trailer arrangements to confirm potential throughput rates and required vessel speed should be conducted.

- Collection of maintenance cost data for commercial vessels in similar routes to reduce the conservatism of the maintenance cost estimates presented in this study.

- Development of a minimum crewing plan consistent with a specific maintenance philosophy and coast guard requirements.

- More accurate assessments of the HMT based on projections of cargo values specific to given routes and markets, and continued efforts to eliminate the HMT.

- In developing a detailed business model the costs of financing, not included in the estimate, must be considered.

- The diversion analysis suggested substantial resistance to SSS on the basis of perceived schedule or reliability disadvantages based on the sample of interviews conducted. SSS costs per load reflected in Tables 5 and 6 are optimistic relative to the diversion analysis results, which would suggest market volumes below the assumed minimum 1400 trailers per day at each terminal in the economic analysis. Any SSS business model will need to address roadblocks to adoption of SSS as an alternate mode.

FIGURE 1: COST PER LOAD BY CATEGORY, NORTHERN CALIFORNIA TO SOUTHERN CALIFORNIA

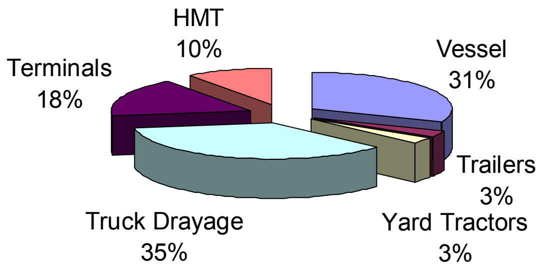


FIGURE 2: COST PER LOAD BY CATEGORY, NORTHERN CALIFORNIA TO PACIFIC NORTHWEST

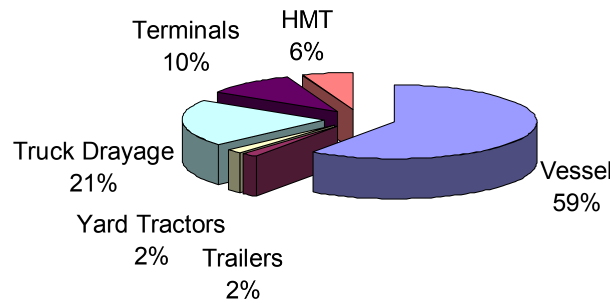


FIGURE 3: COST PER LOAD BY CATEGORY, SOUTHERN CALIFORNIA TO PACIFIC NORTHWEST

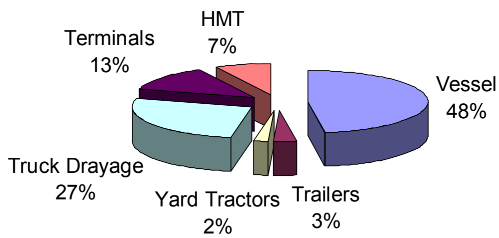


FIGURE 4: VESSEL COST BY CATEGORY, NORTHERN CALIFORNIA TO SOUTHERN CALIFORNIA

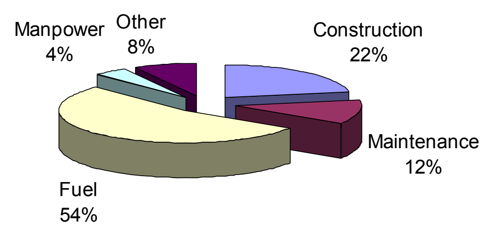


FIGURE 5: VESSEL COST BY CATEGORY, NORTHERN CALIFORNIA TO PACIFIC NORTHWEST

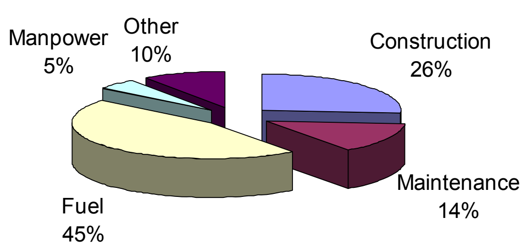
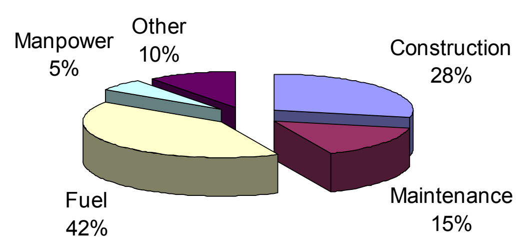


FIGURE 6: VESSEL COST BY CATEGORY, SOUTHERN CALIFORNIA TO PACIFIC NORTHWEST



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2. “Potential Users of Short Sea Shipping.” Manalytics International and CCDoTT, CSULB, Long Beach, CA. May 19, 2006.
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7. “Port and Infrastructure Requirements.” Manalytics International and CCDoTT, CSULB, Long Beach, CA. February 20, 2007.
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Glossary of Acronyms:

BEA - Business Economic Area
BOA - Beam Over All
BWL - Beam at Water Line
CCDoTT - Center for Commercial Deployment of Transportation Technologies
CP - Prismatic Coefficient
L/B - Length/Beam
LOA - Length Over All
LBP - Length Between Perpendiculars
LTL - Less than Truck Load
PNW - Pacific North West
Ro-Ro - Roll-On/Roll-Off
SSS - Short Sea Shipping
VTS - Vessel Traffic Safety